



chiawenl@umich.edu

# Testing semantic compositionality in low-frequency neural oscillations

Chia-Wen Lo & Jonathan R. Brennan

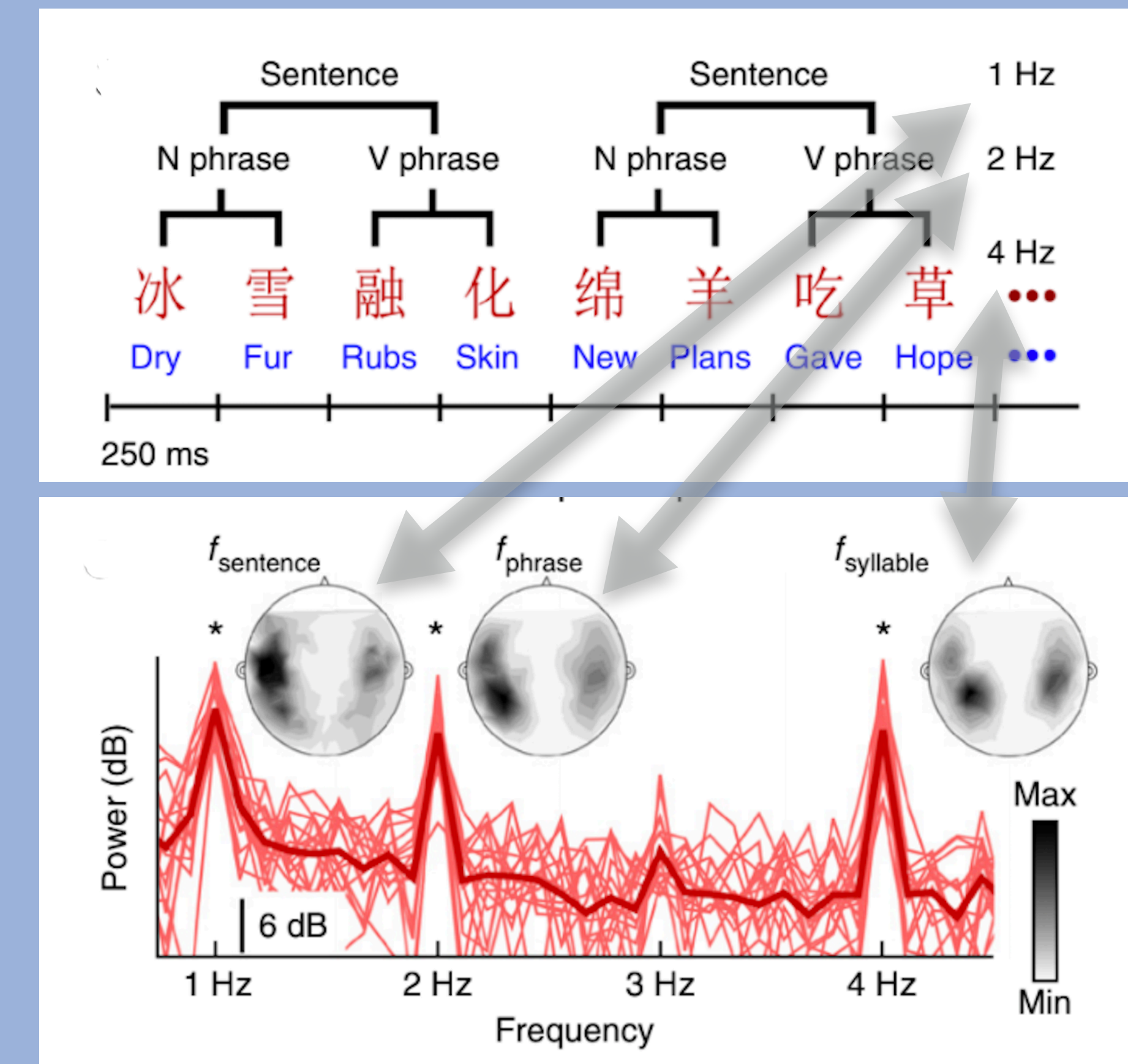
University of Michigan



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## Introduction

Neural responses appear to be entrained to linguistic structures (Ding et al., 2016, 2017). Ding and colleagues (2016) observed cortical tracking of linguistic structures at evoked frequencies corresponding to phrasal (2 Hz) and sentence structure (1 Hz) levels of Mandarin structures in continuous speech presented at a fixed rate of 4 syllables-per-second. Non-Mandarin speakers show syllable effects only when processing the same stimuli.



Stimuli and results from Ding et al. 2016

However, whether delta oscillations are modulated by syntactic information or semantic information is unclear. In addition, the few studies that have linked delta oscillation with semantic processing vary in how they probe semantics (e.g. Brunetti et al. 2013; Mai et al. 2016).

**We use a broad range of different factors to test whether semantic properties might modulate delta oscillations.**

## EEG Methods

### Participant

N = 11 native speakers of Mandarin Chinese listened to 320 trials consisting of ten 4-syllable adjective-noun phrases.

### Procedure

Following the paradigm in Ding et al. (2016), participants were instructed to listen carefully to each trial and judge whether the trial they just heard includes the phrase shown on the screen.

### Recording and statistics

EEG data were recorded at 500 Hz from 32 active electrodes (band-pass filtered at acquisition: 0.01-200 Hz). The first sentence from each trial was excluded to avoid potential EEG responses to sound onset (Ding et al. 2017). Data were manually cleaned of artifacts, filtered from 0.1-25 Hz, and re-referenced offline to common average. For each condition, Evoked Power (EP) and Inter-trial Phase Coherence (ITPC) were computed from 0.5 to 10 Hz in increments of 0.111 Hz. Conditions were compared via two-way ANOVA for each measure in each frequency of interest.

## Semantic variables and stimuli

Plausibility and conceptual specificity were used to define by a 2x2 experimental design. The stimuli were additionally rated for predictability and similarity in order to tease out the separate contribution of these variables.

**Plausibility** The consequence of semantic composition and world knowledge (experimentally manipulated based on offline norm)

**Conceptual specificity** Reflects outcome of composition; (experimentally manipulated, fresh tomato vs. fresh vegetable)

### [+specific, +plausible]

新鲜 蕃茄  
xin-xian fan-qie  
fresh tomato

### [-specific, +plausible]

新鲜 蔬菜  
xin-xian shu-cai  
fresh vegetable

### [+specific, -plausible]

新任 番茄  
xin-ren fan-qie  
newly-appointed tomato

### [-specific, -plausible]

新任 蔬菜  
xin-ren shu-cai  
newly-appointed vegetable

**Predictability** statistical association between words.

Values for all items obtained from Google Chinese BERT by masking the last character of the stimuli.

xin-xian fan \_\_\_\_ "qie": 0.94  
xin-xian shu \_\_\_\_ "cai": 0.16  
xin-ren fan \_\_\_\_ "qie": 0  
xin-ren shu \_\_\_\_ "cai": 0.85

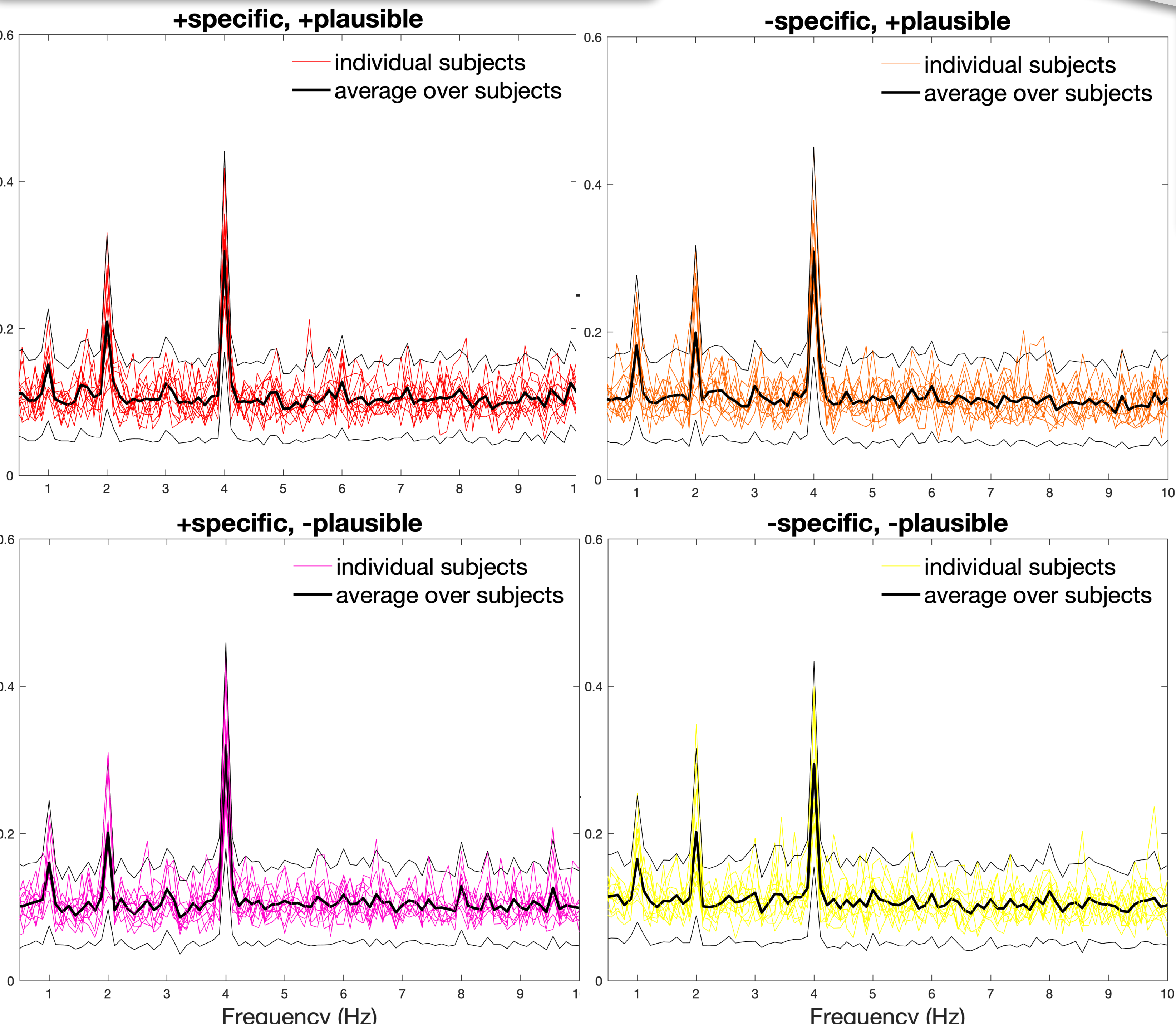
**Semantic similarity** Lexical-level semantic relationship between words

Values for all items computed from cosine similarity by extracting word embeddings from Wikipedia2vec (Yamada et al. 2020).

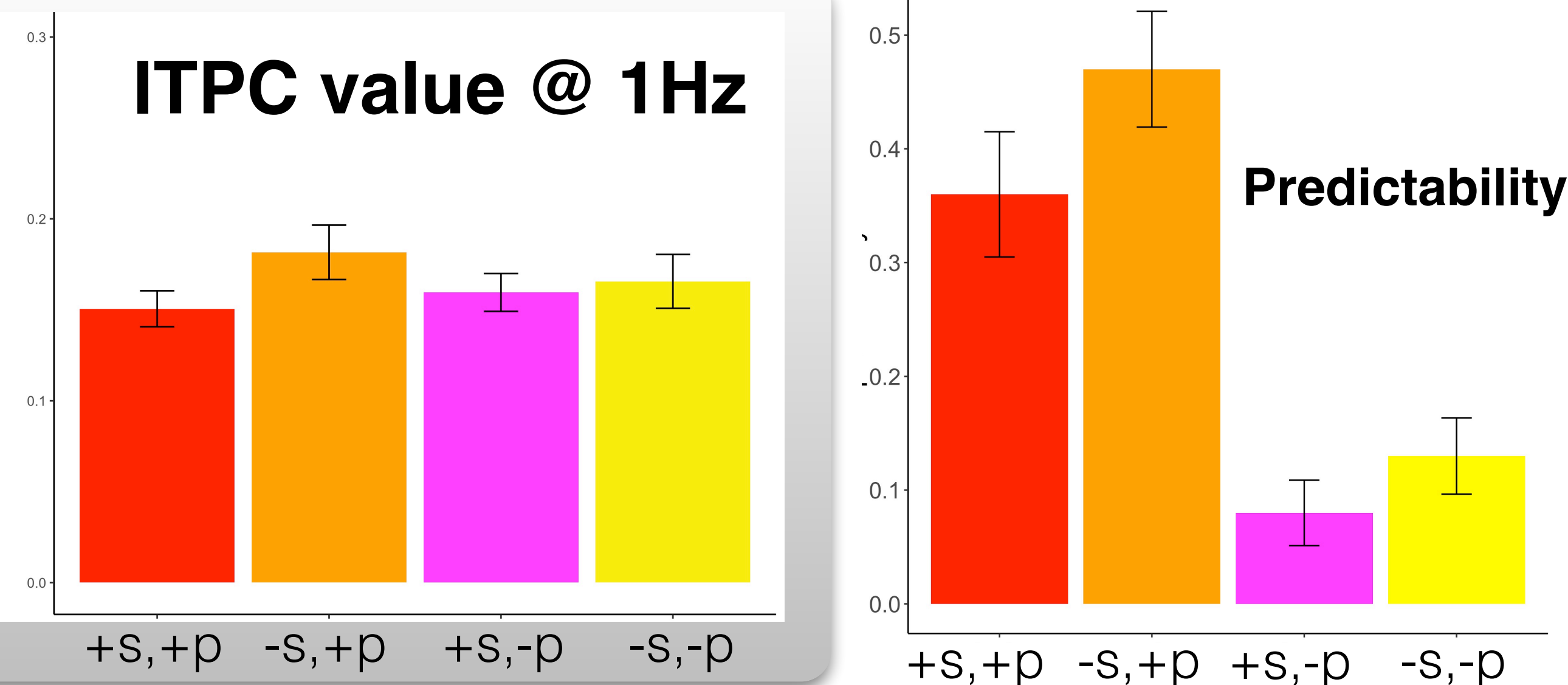
fresh tomato: 0.41  
fresh vegetable: 0.43  
newly-appointed tomato: 0.08  
newly-appointed vegetable: 0.12

## Results

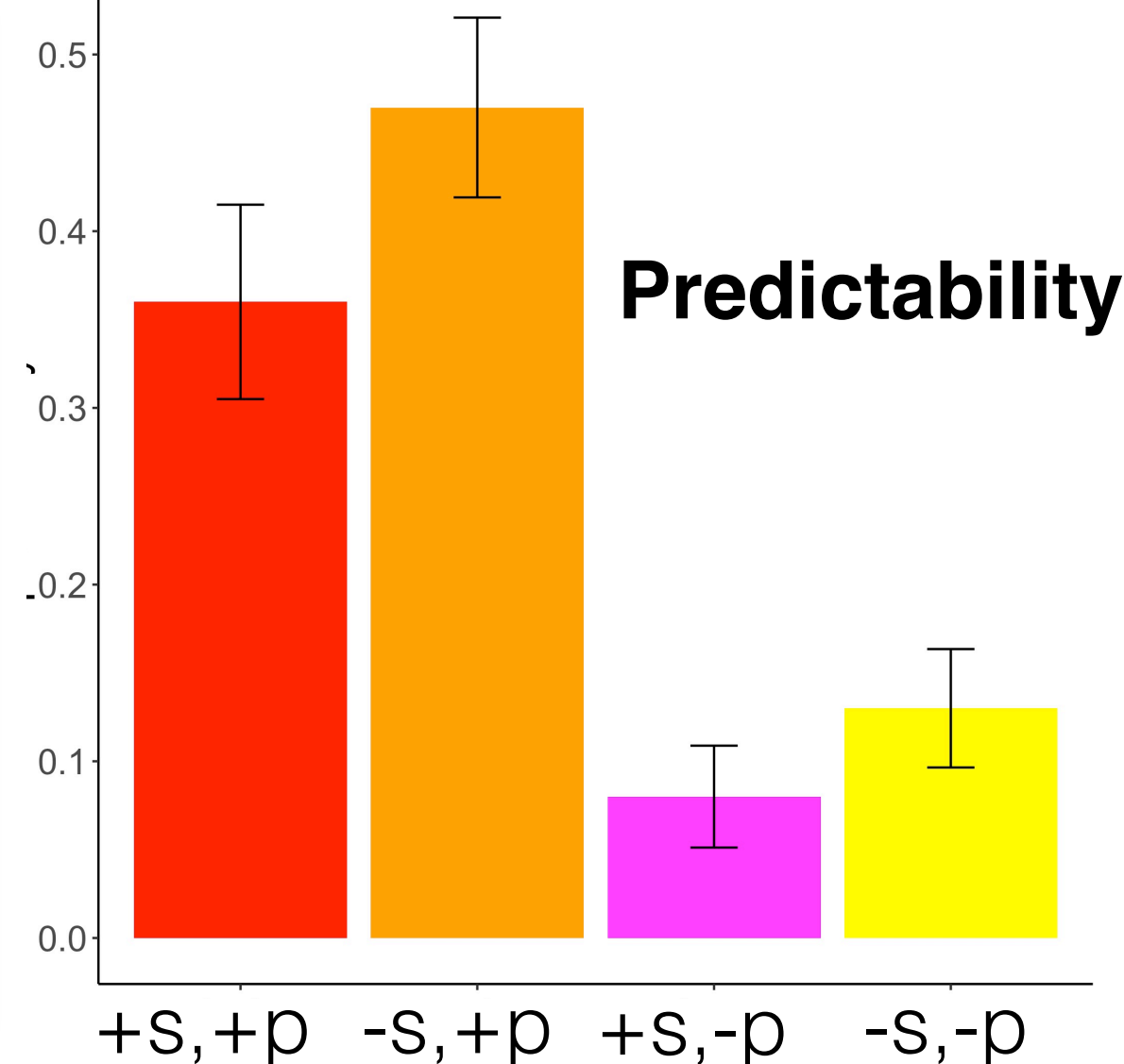
### Inter-trial phase coherence



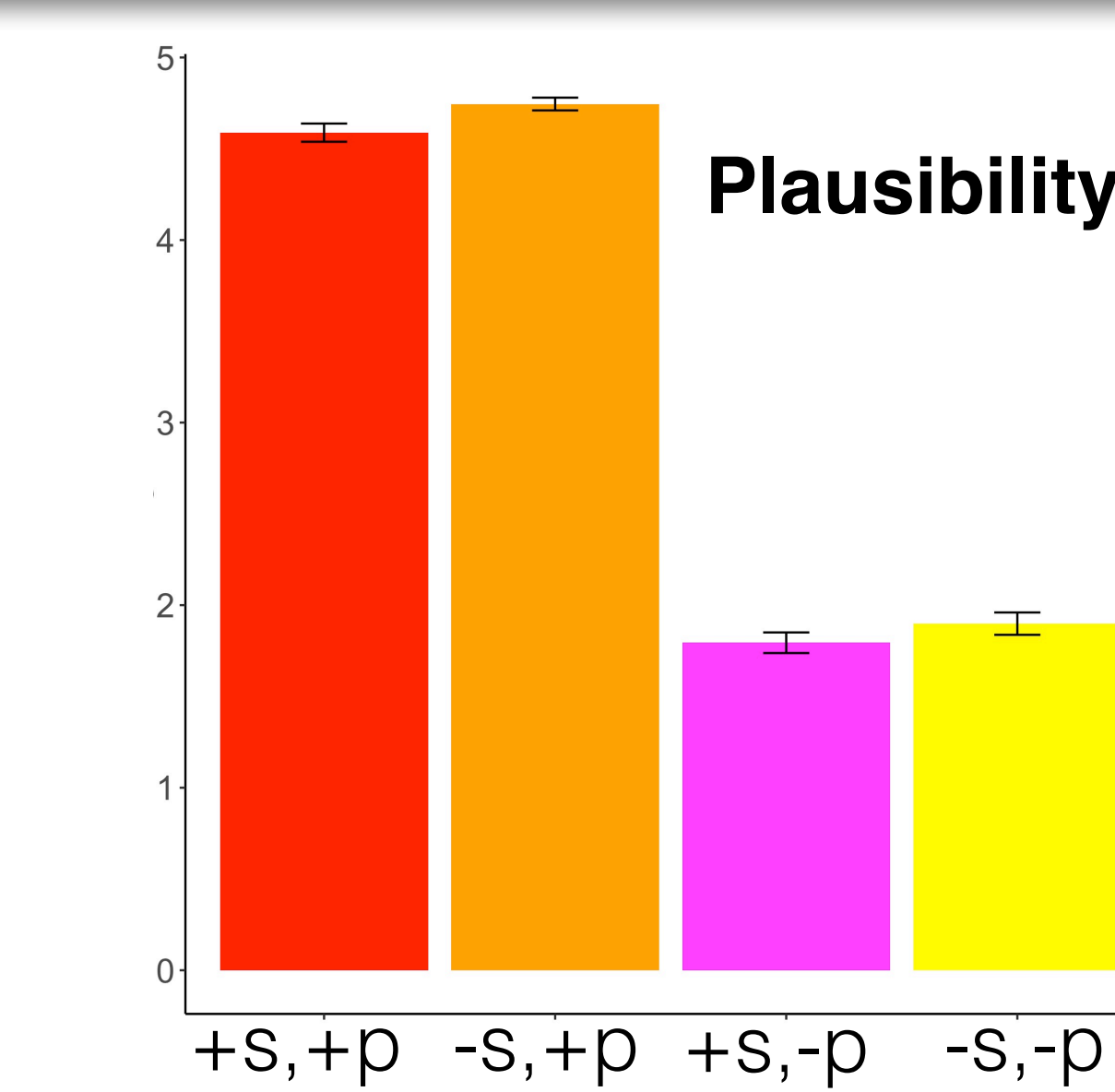
### ITPC value @ 1Hz



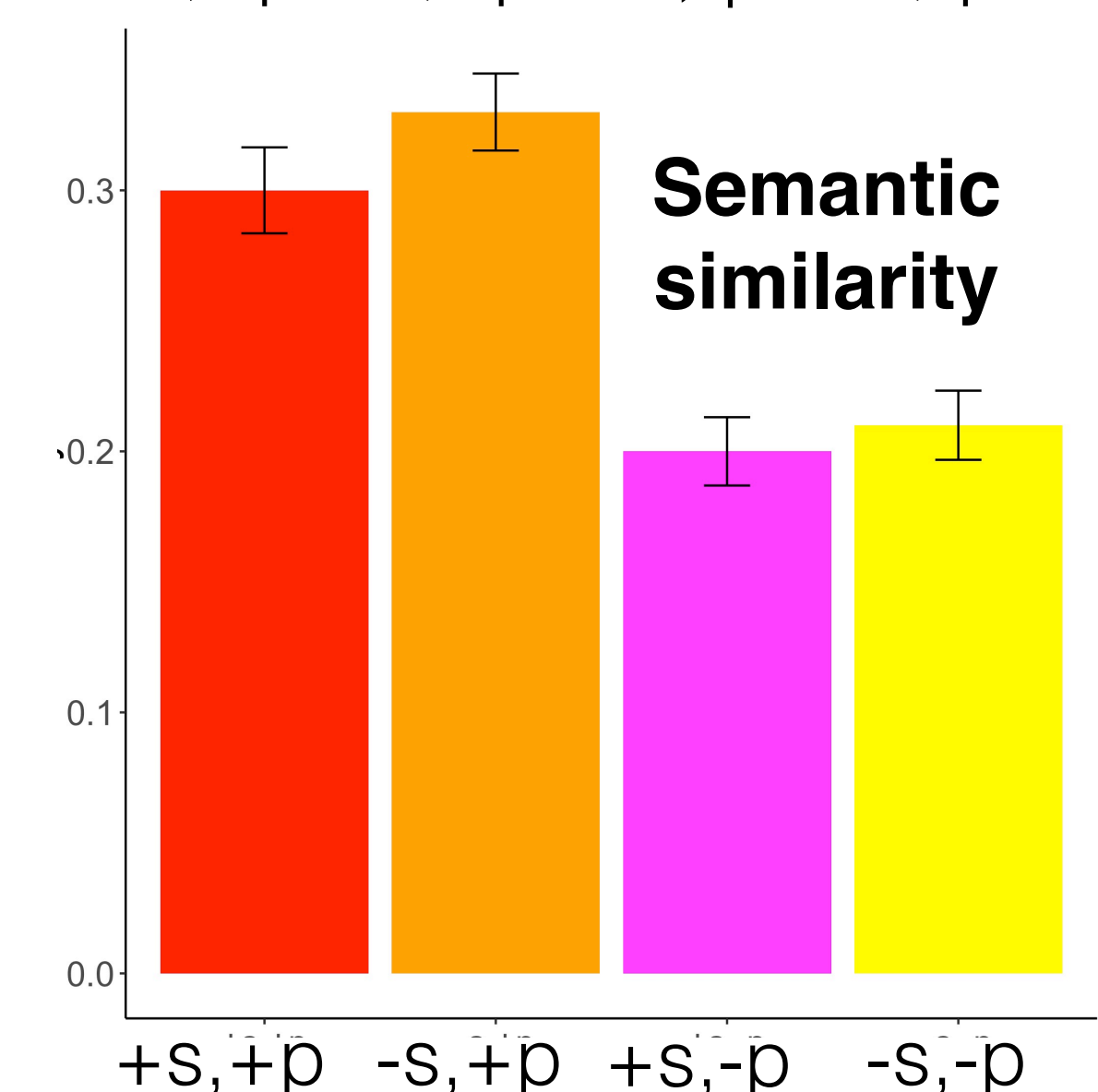
### Predictability



### Plausibility



### Semantic similarity



## Conclusions

- Phrasal peak at 1 Hz found in all conditions for ITPC (shown) and EP
- Trend towards **increased synchronization for non-specific, compared to the specific conditions** (not significant in partial N=11 sample)
- No differences are observed as a function of plausibility, predictability, or semantic similarity