Theta-gamma coupling as an EEG signal for event processing in language

Introduction

What do we represent in our minds when we process events in language? Altmann and Ekves (2019) proposed that events comprise objects and their histories (i.e. in the sentence “the chef chopped the mango”, we simultaneously represent both the intact and chopped mango). There is fMRI evidence of competition between these object-states in the left ventrolateral prefrontal cortex (Hindy et al. 2012; Solomon et al. 2015). However, little is known about the dynamics of these representations and how they are maintained simultaneously in the brain. Here we propose a neural code for event representation: theta-gamma phase-amplitude coupling (henceforth PAC). PAC occurs when neural oscillations of two different frequencies are coupled together. That is, the amplitude of a fast gamma wave waxes and wanes at the frequency of a slower theta wave. In temporal regions of the brain, the signal has typically been associated with working memory – for example, the strength of theta-gamma coupling increases with working memory demands (e.g. Heusser et al 2016, Reinhart and Nguyen 2019). What the individual oscillations represent is less clear, but one hypothesis is that PAC functions to sequentially encode multiple items in working memory (Lisman 2005). PAC may thus be a neural signal of events in one of two ways. On one hand, we might observe greater PAC when objects undergo substantial change, reflecting the encoding of multiple distinct object-states sequentially in working memory. Alternatively, PAC might increase in events which incur minimal change instead, representing the increased working memory demand of distinguishing two featurally similar object-states. This abstract presents PAC analyses of data from two existing experiments on events in language. We hypothesized that PAC would increase in the substantial change condition (e.g. “the chef chopped the mango”; corresponding to more distinct object-states) but not the minimal change condition (e.g. “the chef weighed the mango”).

Methods

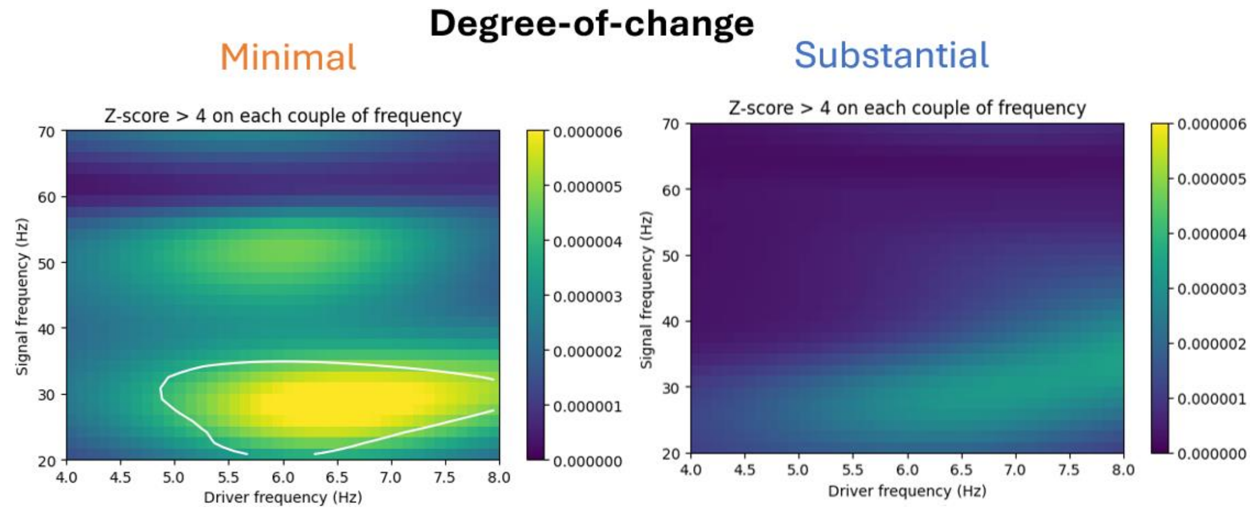
In both experiments (1: N=45; 2: N=31), participants read English sentences on a screen word-by-word (ISI: 600ms) while having their EEG data recorded. Stimuli consisted of 2 sentences each – in the first sentence, an object underwent either substantial or minimal state change, and in the second sentence, it was referenced again (e.g. “The woman will bite the plum. And then, she will squeeze the plum.”). EEG was recorded using 256-channel EGI HydroCel Geodesic Sensor Nets at a sampling rate of 1000 Hz. Raw data was bandpass filtered at 1-80 Hz then downsampled to 250 Hz. 7.2-second (12-word) epochs were extracted from a left temporal electrode (T7) following the onset of each trial. Data from both experiments was combined, and PAC at this channel was then quantified by a Driven Auto-Regressive (DAR) model (Dupré la Tour et al 2017) and z-scored using 200 surrogates.

Results

There was significant theta-gamma phase-amplitude coupling (6-7 Hz and 30 Hz; $p < 0.01$) in the minimal change but not substantial change condition. Follow-up analyses using a cluster of electrodes, rather than a single channel, around the left temporal area showed the same pattern of results.

Summary

Theta-gamma PAC is a promising correlate of event processing in language in the brain. We propose that events which incur minimal change also require finer representational distinctions to maintain separable versions of the same object across the event. These distinctions, reflecting the trajectory of the object through time, are diagnostic of the event itself. Thus maintaining diagnosticity in the face of greater representational overlap imposes additional working memory demands, which manifests as increases in PAC.



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