Oscillatory Dynamics to Time-stretched Speech during Lexical Decision

Jonathan Brennan[1], Constantine Lignos[2], Max Cantor[1], David Embick[3] & Timothy P. L. Roberts[2,3]

jobrenn@umich.edu

[1]University of Michigan, [2]Children's Hospital of Philadelphia, [3]University of Pennsylvania

Introduction

Neurophysiological models of spoken word recognition implicate peri-auditory activation within the first few hundred milliseconds after stimulus onset (Friederici 2012), however the mechanism by which these regions incrementally map spoken stimuli on to candidate lexical entries remains poorly understood.

Recent attention to neural oscillations suggest that alpha-centered power reduction (event-related de-synchronization; ERD) beginning between 250-300ms after stimulus onset reflects early stages of lexical processing (e.g. Wang et al. 2012; Brennan et al., 2014); left unspecified is **whether this activation is sensitive to the onset of lexical activation (*reduced power = earlier activation*) or the speed of activation (*reduced power = more rapid lexical convergence*)**.

We predict that stimuli with more rapidly presented cues will lead to early onset of lexical activation. We quantify the mapping of speech cues to lexical identity using *cohort entropy*, an information theoretic measurement of uncertainty over possible lexical items given partial speech input. Recent work has shown that cohort entropy correlates with evoked activity in peri-auditory cortex with a 200ms lag (Ettinger et al. 2014)

Using magnetoencephalography (MEG), we test for oscillatory dynamics sensitive to lexical activation onset; **using time-stretched speech we manipulate the speed that sub-lexical features incrementally unfold while keeping lexical identity constant.**

We find that alpha power and gamma coherence are sensitive to time-stretched speech; cohort entropy and power in the alpha, beta, and gamma range correlate at latencies suggesting that these components may reflect later stages of lexical processing.

Methods

Stimuli 132 mono-syllabic high frequency nouns and 165 matched psedo-words, recorded by a female speaker, were time-stretched to **80%** and to **120%** of their original duration keeping pitch unchanged (PSOLA). Median length of the original stimuli was 479ms and the median change was ± 94ms.

Cohort Entropy was estimated phoneme-by-phoneme using SUBLTEX-US frequency norms and the lexicon and pronunciations of the English Lexicon Project. Prosodylab-aligner was used to time-align entropy measures for each stimulus.

Participants & Design 16 adult participants listened to a random sampling of 100 tokens each of 80%, 120%, or original 100% stimuli and 100 pseudo-words while performing a lexical decision task. An auditory localizer using 120 1kHz tones was also administered.

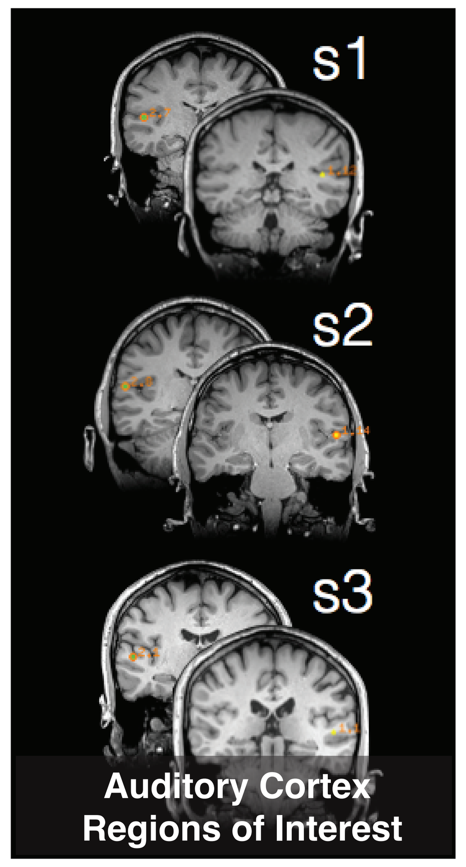
Data Collection Neural activity was recorded at 1200Hz using MEG with 275 gradiometers (CTF, VSM). Anatomical images of each participants' brain were collected using MRI (GE). Data from one subject was excluded due to recording error. Trials with visually-identified noise, behavioral errors, or duplicated stimulus presentation were excluded.

Evoked and time-frequency representations from auditory cortex were compared by time-stretch condition and single-trial analysis was conducted to test for correlates of cohort entropy.

Neurobiology of Language, August 2014, Amsterdam

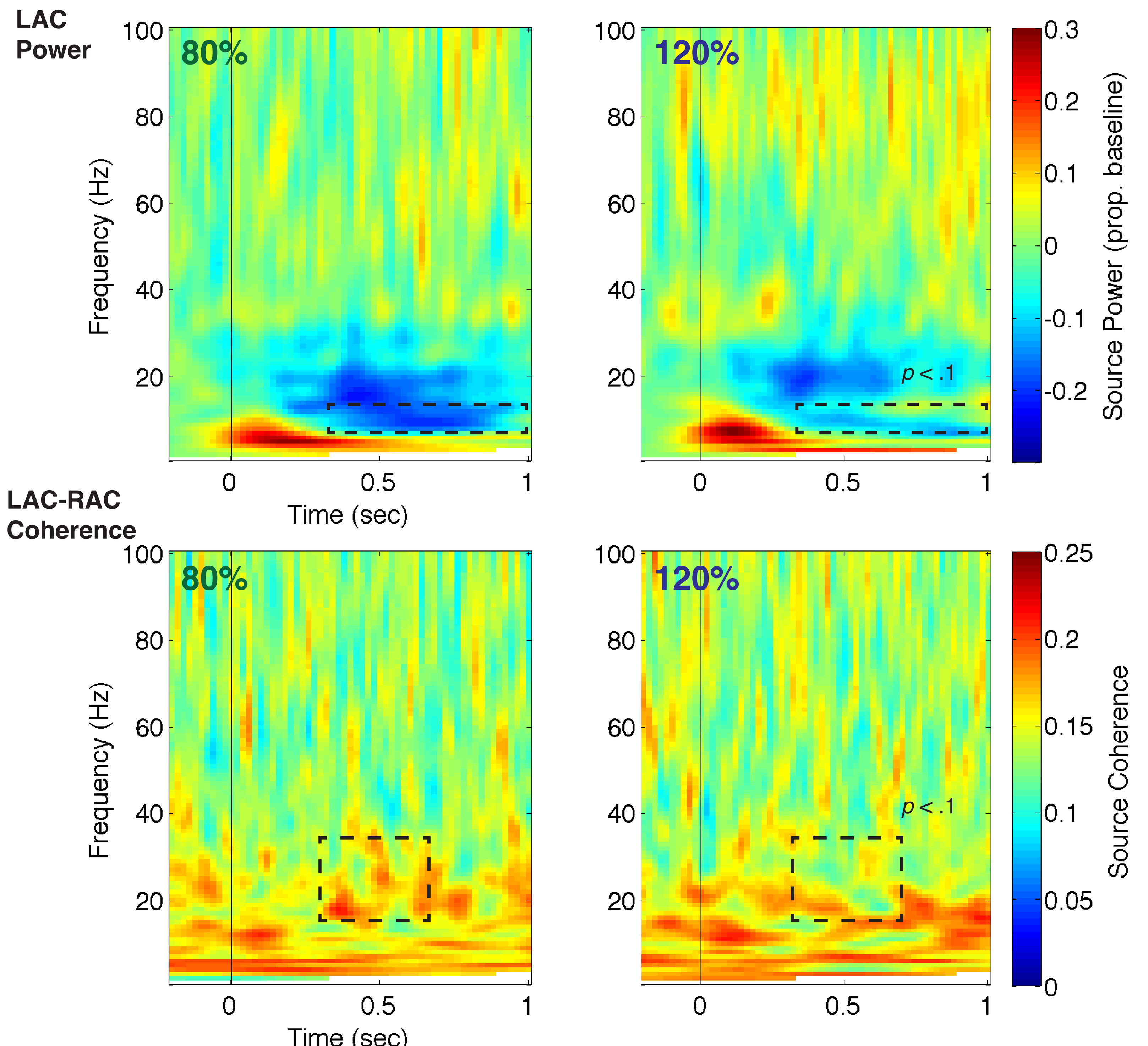
Results: Peri-auditory Dynamics

Lexical Decision Results Using mixed effects models, we found RTs were linearly related to stimulus length ($p < .001$) with no additional effect of time-stretching ($p > .15$). Importantly, accuracy was matched for 80% and 120% stimuli and was high overall (>95%; $p > .1$). Lexical entropy correlated with RTs, with the best-fitting values lagged 105ms from stimulus onset ($p < .001$).



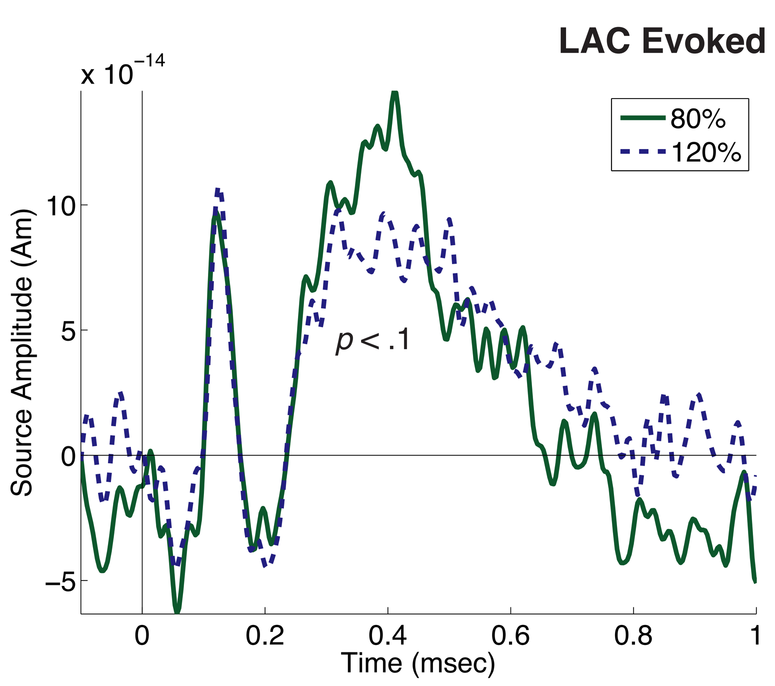
MEG Data Analysis Head-models for each subject were constructed based on their anatomical MRI. Left and right auditory cortex (AC) was identified in each participant using a multi-dipole model fit to the auditory M100 response from 120 1kHz tones.

Auditory cortex responses to target words were estimated using SAM beamforming. Responses to **80%** and **120%** stimuli, both subject to digital manipulation, were either band-pass filtered from 0.5-40Hz and averaged (evoked response), or converted to time-frequency representations between 1-100Hz in 20msec increments (morlet wavelets, width = 7) and compared using a cluster-based permutation test (Maris & Oostenveld 2007).



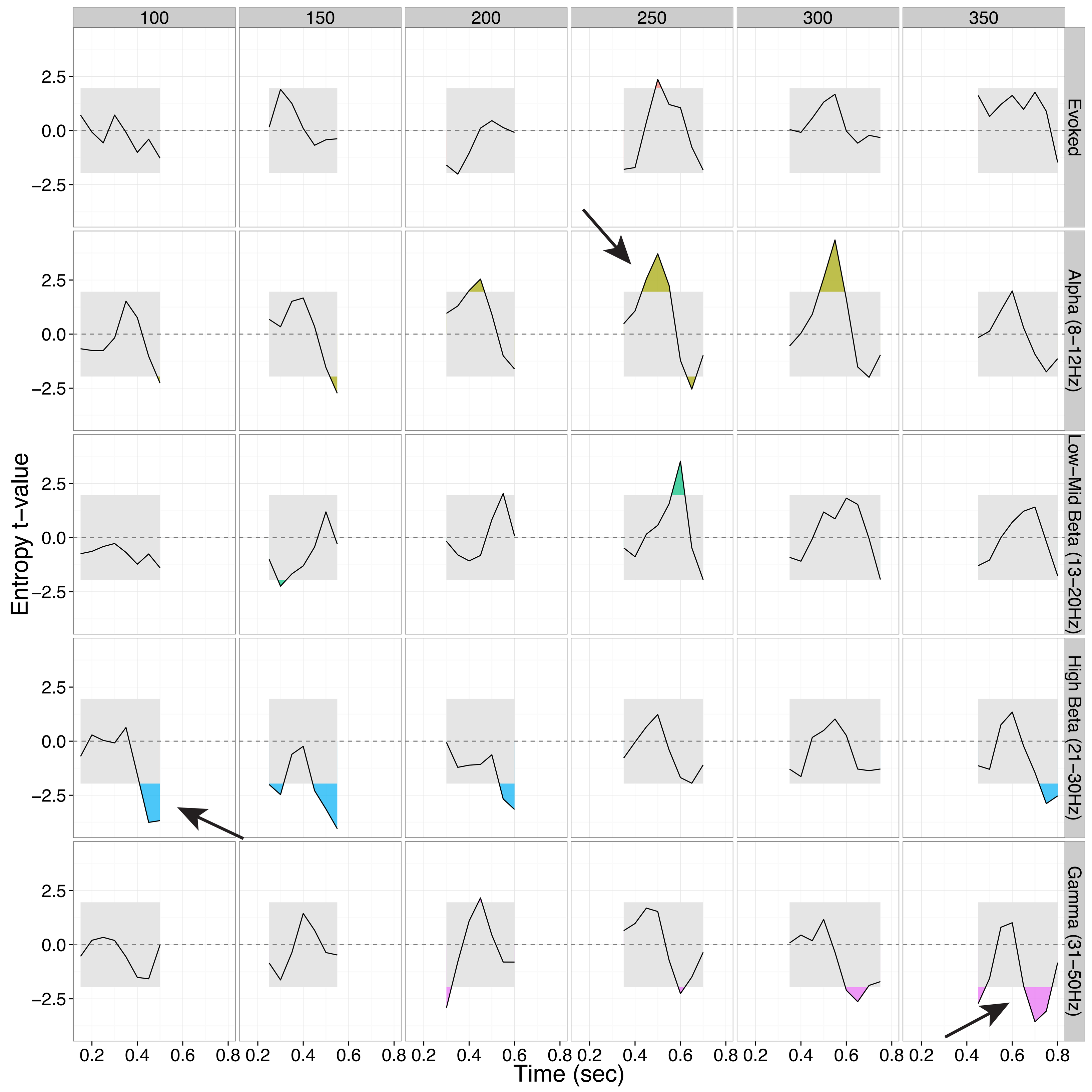
Early auditory components and late sustained effects found in both evoked and time-frequency responses, including alpha-beta range ERD beginning around 250ms. **No significant effects of word compression** at standard thresholds.

Marginal effects relatively late were found beginning around 400ms (evoked: 375-425ms; power: 400-1000ms @ 10-15Hz; coherence: 400-700ms @ 20-35Hz)



Results: Single-Trial Analysis

Correlation Analysis Trial-level values including *cohort entropy* at varying lags, *compression level, duration, lexical frequency, repetition, trial order,* and a third-order polynomial for time were fit using mixed-effects models against evoked and time-frequency representations for all target words (100% intercept) in 100ms sliding-windows averages (step size = 50ms) (e.g. Hauk et al., 2006).



Cohort entropy effects on high-beta, alpha, and gamma power after 400ms at distinct lags; no earlier effects nor effects on the evoked response.

Conclusions

Time-stretched speech appears to impact late evoked (~400ms) and time-frequency responses (alpha-band power, gamma-band coherence), though effects not robust. Fragility of effects may reflect efficient normalization against temporal manipulations during speech recognition.

Single-trial results show incremental lexical information (*cohort entropy*) affects alpha ERD, beta ERD and gamma power after 400ms at different lags, suggesting that these components may reflect different sub-processes. Timing indicates that the observed changes in power reflect late stages of lexical access, not the onset of lexical activation.

Bibliography Brennan et al. (2014) *Brain and Language*, 133, 39–46.; Ettinger et al. (2014). *Brain and Language*.; Friederici (2012). *Trends in Cognitive Sciences*, 16(5), 262–268.; Hauk et al. (2006). *NeuroImage*, 30(4), 1383–1400.; Wang (2012). *Hum Brain Mapp*, 22(12), 2898–2912.