A Coupled Oscillator Planning Account of the Speech Articulatory Coordination Metric With Applications to Disordered Speech

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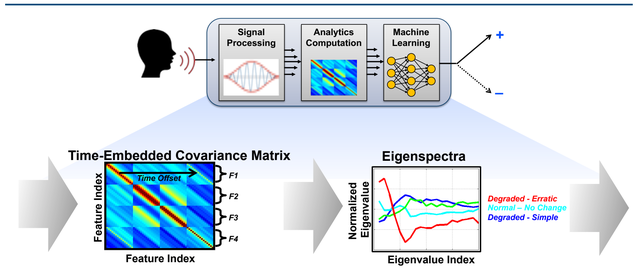
Objectives

Our long-term objective is to develop a theoretical foundation for the speech articulatory coordination (SAC) metric using Articulatory Phonology (AP), based on coupled oscillator models of syllable organization.

In this work, we specifically aim to use AP-based simulations to demonstrate that:

- **SAC metric is sensitive to changes in gestural relative phase**
- **Gestural competitive coupling and consistency induce changes in gestural relative phase**

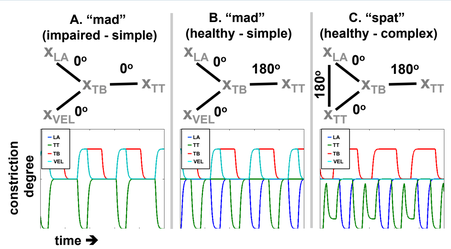
Speech Articulatory Coordination Metric



The SAC metric: (Williamson, 2019)

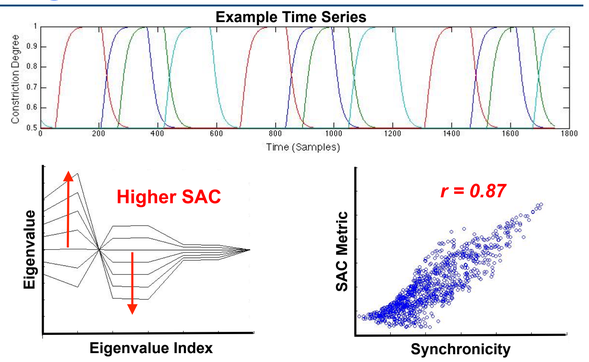
- Has shown promise as a measure of motor changes in a variety of health-related neurological conditions
- Has been described as a measure of speech articulatory coordination
- Is primarily sensitive to differences in relative gestural phase and frequency

Articulatory Phonology, Gestural Coupling & Gestural Phase

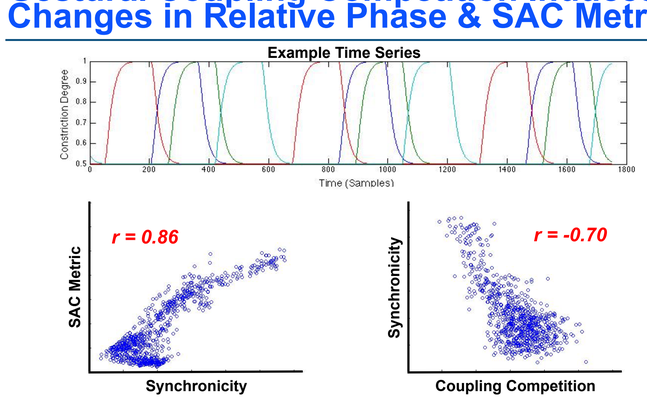


- Articulatory Phonology posits that gestures are the fundamental units of organization in spoken language (Saltzman & Munhall, 1989; Browman & Goldstein, 1992)
- Temporal patterning of speech gestures has been modeled using coupled oscillator models of coordination (e.g., Haken et al., 1985; Goldstein et al., 2009)
- Differences in coupling competition lead primarily to differences in the relative phase of speech gestures

Gestural Relative Phases Induce Changes in SAC Metric



Gestural Coupling Competition Induces Changes in Relative Phase & SAC Metric



Gestural Organization Simulations

Three Conditions

1. **fixed relative phase, randomly selected**
2. **fixed coupling competition, randomly selected**
3. **time-varying gestural coupling, random**

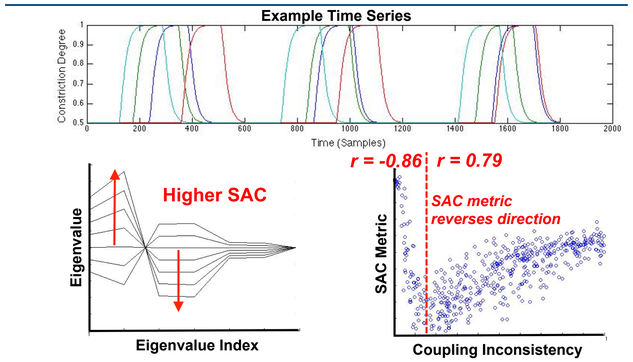
Simulation Parameters

- **Four oscillators**
- **Bidirectional coupling**
- **Gestural frequency fixed, equal**

Measured Quantities

- **SAC metric – score along first principal component of eigenspectrum variations in condition #1**
- **Synchronicity – root-mean-square deviation from max relative phase spacing**
- **Inconsistency – parameterized time-varying random noise in the coupling relationships**
- **Coupling competition – mean of coupling matrix values**

Coupling Inconsistency Induces Nonlinear Changes in SAC Metric



Conclusions & Open Questions

Conclusion #1: The SAC metric is a promising measure of coordinative patterns in speech articulation, with demonstrated applications to neurological, cognitive and psychological health.

Conclusion #2: This study provides the first evidence that the SAC metric is more than an advanced signal processing method, and has theoretical foundations in AP

Conclusion #3: The SAC metric is sensitive to gestural relative phase, and can be seen as a measure of the synchronicity of speech gestures

Conclusion #4: Gestural competitive coupling and consistency induce changes in gestural relative phase, and therefore represent a candidate causal explanation for variation in the SAC metric

Question: Is there a method for directly predicting relative phases of weakly coupled oscillators? We are skeptical of our own coupling competition metric used here.

Question: Does AP and coupled oscillator theory imply any other coordination metrics that might be more powerful that SAC?

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