Simulating Tonic/Postural Activations in Speech Production

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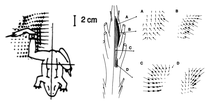
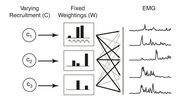
Studies of speech production have often focused on transient events – those that happen over short temporal intervals. We know, however, that speech is made up of movements that can be distributed over longer durations as well (e.g., tongue bracing, oralization, articulatory setting, laryngeal state, harmony, etc.). Such events, which involve maintaining continuous activation of a particular muscle group tonically over a long duration, have often been treated as qualitatively different from transient speech events. The present study considers examples of these types of movements in speech and non-speech (e.g., emotion expression, posture, etc.) domains. Biomechanical simulations are used to show how tonic activations operate on the same principles as transient ones (except for the difference in duration), and to show how tonic activations can overlap with multiple other activations – whether transient or tonic – through superposition [Bizzi et al. 1991, Science 253: 5017]. This work aims to show how these previously anomalous kinds of movements fit seamlessly into broader theories of movement and speech [funding from NIH Grant DC-002717; NSERC RGPIN-2015-05099].

Introduction: Synergies, Posture & Superposition

- Spatially Fixed Muscle Synergies (SFMS, Safavynia and Ting 2012)
  - Neuromuscular *modules* are functionally defined in the nervous system to govern a basic, natural body action (e.g., Berniker et al., 2009).

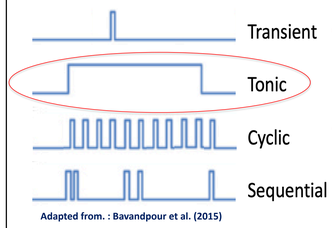


Bizzi et al's. (1991) "spinalized frogs"



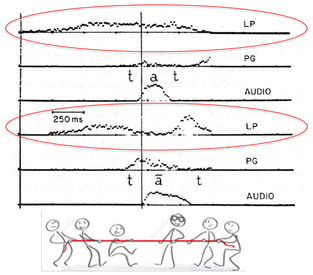
Safavynia & Ting's (2012) SFMSs

- Different temporal types:



Adapted from. : Bavandpour et al. (2015)

- "Orality" as tonic setting (Benguerel 1977):



- Overlapping Innervation Wave Theory (Joos, 1948)

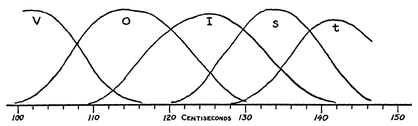


Fig. 38. Overlapping innervation waves

We use biomechanical simulation to test superposition of tonic/postural devices in 3 contexts:

Local: coarticulation in adjacent sounds (e.g., aka vs. iki)
- Simulate/replicate EMA results of Recasens & Espinosa (2009)

Non-local: long-distance interactions (e.g., /sis/, /sas/)
- Simulate effect across intervening segment(s)

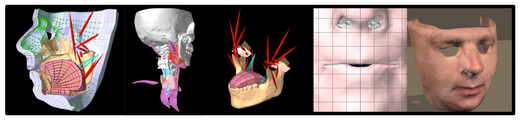
Emotion Expression:
- affects every sound in a language
- cf. articulatory setting (Gick et al. 2004)

NB: *We use no explicit model of coarticulation – just a body*

Simulation Methods

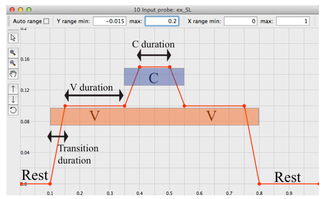
Biomechanical Modeling using Artisynth
- 3D finite-element method (FEM) model; www.artisynth.org (Lloyd et al., 2012)
- FEM dynamics enables realistic collision detection and tissue compression

Simulation methods
- Vowels/sibilants:
  - Jaw-hyoid-tongue model (Stavness et al. 2012)
- Facial expression:
  - FEM face model

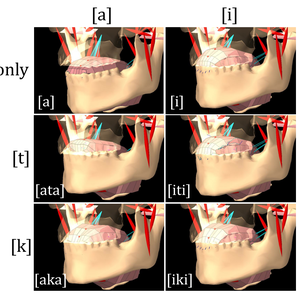


Simulation results

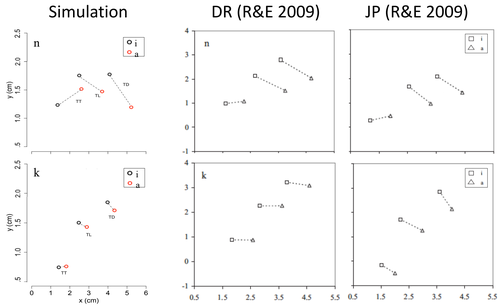
Tonic/Postural Vowels (local overlap):



Schematic control diagram for VCV simulation
VCV simulations from Gick & Stavness (2013)



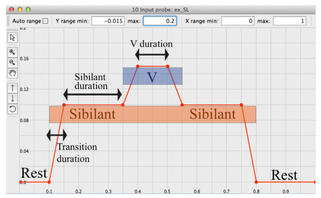
Simulated postures from VCVs; red pellets on the tongue surface represent simulated EMA transducer coils used to track flesh points



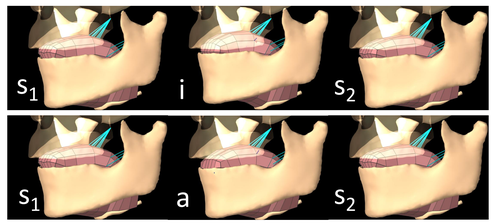
Tongue tip (TT), tongue blade (TL) and tongue dorsum (TD) points at VCV consonant midpoints, from simulations (left) and EMA (adapted fr. Recasens & Espinosa 2009)

Tonic/Postural Sibilants (non-local overlap):

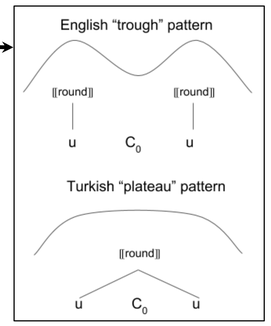
Harmony can work the same way (cf. Turkish labial harmony, e.g. Boyce 1990)
Segmental content of intervening material is irrelevant



Schematic control diagram for SVS simulation

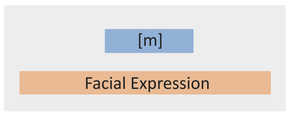


Simulated SVS postures

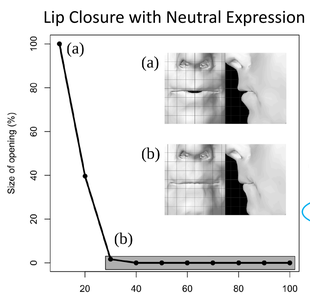


Schematic representations of lip rounding in English and Turkish; curve represents degree of lip protrusion (adapted from Kaun 2004)

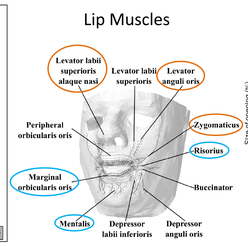
Tonic/Postural Emotion Expression: Smile vs. Lip Closure (global overlap)



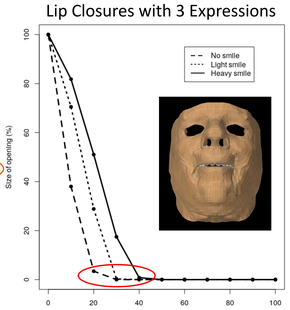
Schematic control diagram for facial expression with temporally overlapping lip closure



Simulated lip closure overlapping with neutral face posture (adapted from Gick & al. under review)



Muscles used for simulation:
smile muscles circled in orange;
closure muscles circled in blue
(adapted fr. Gick & al. under review)



Simulated lip closure overlapping with 3 different face postures

Discussion

- Tonic/postural activations are pervasive in speech
- Superposition works across different scales with *no extrinsic model of coarticulation*
- Built-in mechanics of the human body can handle coarticulatory interactions with simple overlap
  - no advance planning
  - no contextual information
- Simple temporal overlap of muscle activations in a biomechanically realistic simulation produces plausible, idiosyncratic coarticulation patterns
  - Locally (shown for canonical VCV combinations)
  - Non-locally (shown for sibilant harmony)
  - Globally (shown for emotion expression)
- "Tug-of-war" requires greater activation to achieve lip closure

FUTURE WORK:
- Continue to seek examples of tonic/postural devices in speech
- Continue EMG validation studies
- Simulate a wider range of phenomena (e.g., articulatory settings, laryngeal states, etc.)
- What about *SUPPRESSION/INHIBITION*?

References

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