



Temporal coupling between speech and manual motor actions

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Abstract

Speech production is part of the larger motor control system, and as such can be organized into coordinative structures with other motor behaviors that can then be parameterized as single functional units. Previous work has shown the magnitude of movements in coordinated speech and finger tapping covaries across repetitions. The current study expands on this previous work to examine the temporal coordination of these coordinated movements. Subjects repeated a spoken syllable while tapping their finger in time with their speech. On each trial, they placed an emphatic stress on a single repetition of either a spoken syllable or a finger tap, and were instructed to maintain their production in the other domain unchanged. Results show that explicit stress in either speech or finger tapping generally lengthens the stressed repetition in that domain as well as the synchronous repetition in the other domain. Additionally, stress of either a spoken syllable or finger tap causes some lengthening of the interval between repetitions in both domains. This cross-domain covariation of the interval between repetitions extends to unstressed repetitions as well. These results indicate that control of prosody may be defined over a wide set of articulatory components, not just the speech motor system.

Background

Kelso, Tuller, & Harris (1983):

- Subjects were instructed to repetitively speak a word and tap their finger in time. When subjects stressed the spoken word, they produced larger finger movements **despite instructions to maintain the finger tapping constant**; subjects also showed a greater acoustic intensity on spoken syllables when stressing a finger tap, despite instructions to maintain the speech at a constant level.

Parrell et al (2010):

- Similar task as above. Found covariation of movement magnitude between finger and speech articulators even in the **absence of explicit stress**.

Smith, MacFarland, & Weber (1986):

- Examined temporal coordination in a rhythmic speech and tapping task without explicit stress. Found consistently aligned productions (within 1/4 cycle) between the two domains.

Evidence that **speech articulators are an integral part of the general motor control system** and, as such can enter into functional coordinative structures with other motor components.

BUT: how does stress effect temporal coordination?

- Stress has large temporal effects in speech (e.g Beckman & Edward 1994, Byrd et al 2006)
- Rhythmic tapping has its own temporal patterns (Nagasaki 1987)

Study goals

- Test **temporal** effects of stress on the data that was previously shown to demonstrate **spatial** entrainment of speech and manual motor movements.
- Examine whether entrainment of speech and non-speech actions extends beyond effects of large, explicit stress.
- Pursue implications for showing how production of speech prosody can be understood in terms of general control of human motor movement..

Methods: Data Collection

- Articulatory data was collected using a 3-D electromagnetic articulometer (Carstens AG500).
- Transducers were adhered to the upper and lower lips, and the tip of the right index finger.

Methods: Procedure

- Four subjects (TA, TB, TC, TD).
- Subjects (all right handed) tapped their right finger on their left shoulder while repeating a monosyllabic word (*ma* or *mop*) in time with their finger taps (Figure 1)
- Subjects were presented with a modified clock face (figure 2), on which a second hand swept continuously in the clock-wise direction. Subjects began production of finger tapping and speaking at the sweep of the second hand past a star when signaled by the experimenter and continued until the next star, i.e. for a 15 second interval



Figure 1: Subjects tapped their finger in time with repetitions of a target word.

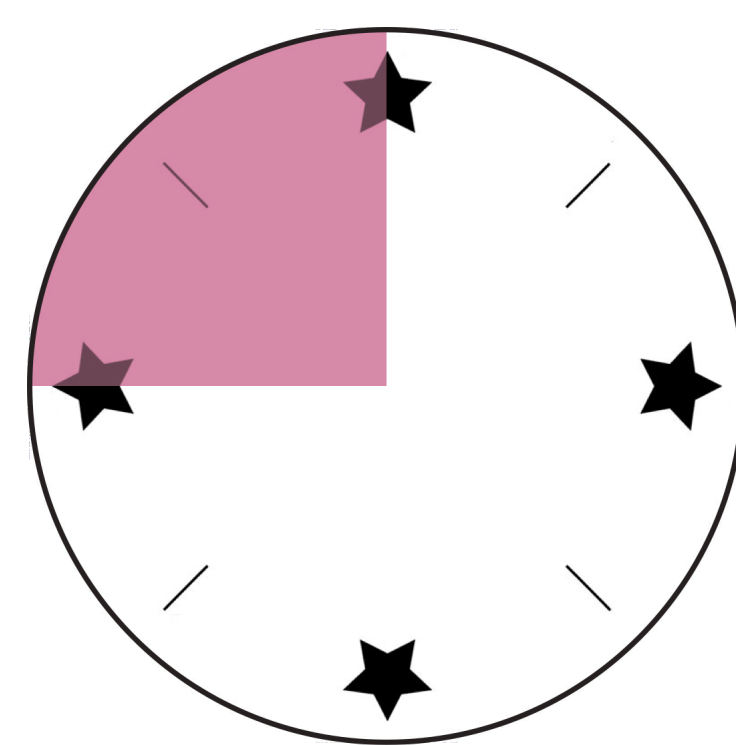


Figure 2: Elicitation clock face. Data collection area in red.

- When the second hand was at or near the halfway hash mark, subjects either (in condition 1) made a single finger tap movement emphatic or (in condition 2) placed an emphatic stress on one repetition of the spoken syllable.
- In both cases, **subjects were explicitly instructed to maintain the unemphasized action (tap or syllable) completely unchanged, continuing to repeat it at a constant, even rate.**

Methods: Data Measurement

Euclidean Lip Aperture (LA) was calculated as the distance between the sensors on the upper and lower lips.

For the fingertip (FT), the point of maximum constriction was measured when the finger was touching the shoulder; so the motion of the finger towards that target constituted the relevant part of the movement

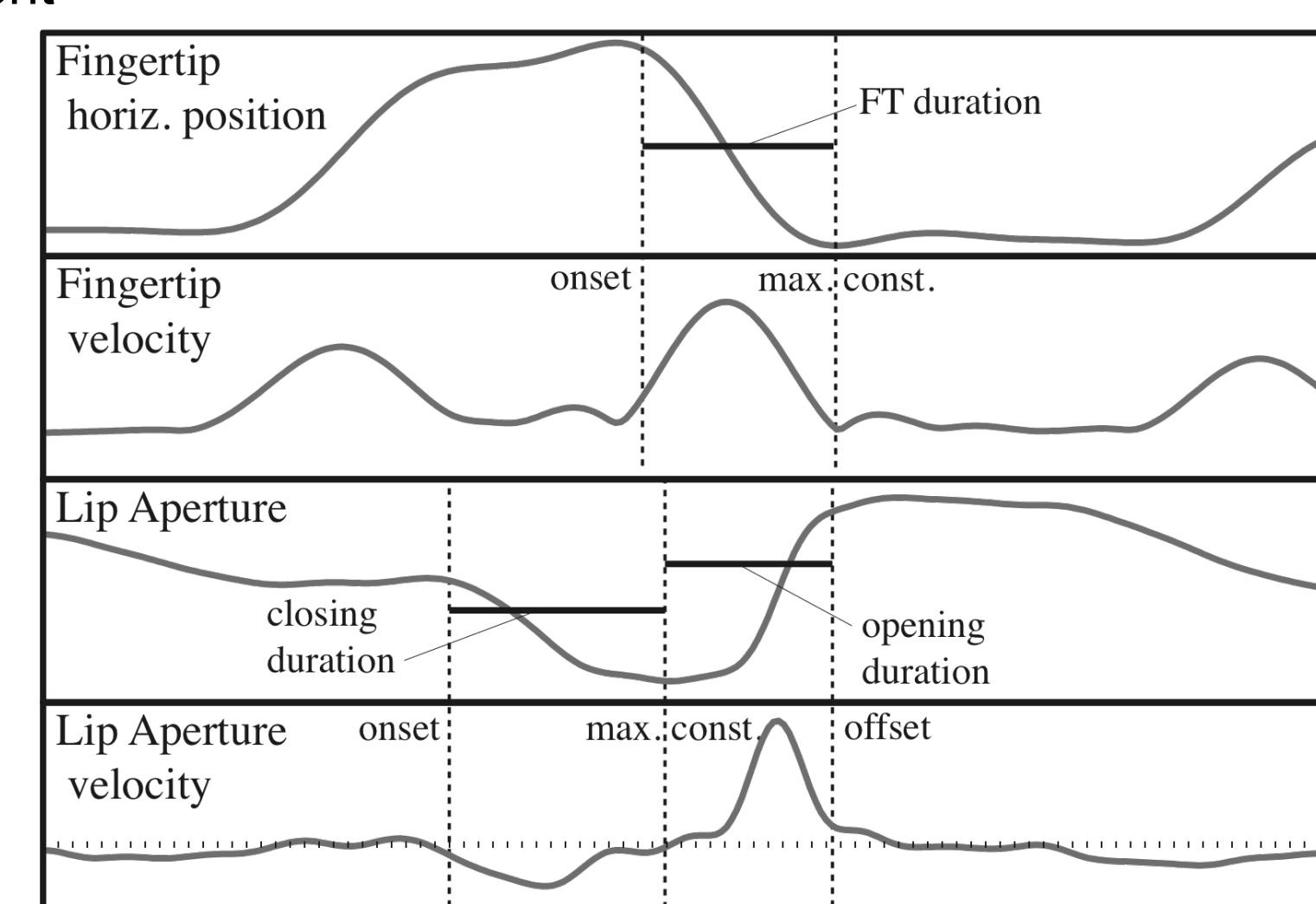


Figure 3: Measurements taken from articulatory data. Horizontal position of the finger shown for illustration only; all movements were measured from the 3D tangential velocity

Results: Duration

Duration of stressed repetition compared against the mean of all unstressed repetitions for each trial. LAC = lip closing movement, LAO = lip opening movement.

SAME action explicitly stressed:

Subject	Spoken Stress (Effect on LA)	Tapped stress (Effect on FT)
TA	✓ LAC, LAO	✓
TB	✓ LAC, LAO	✗
TC	✗	✗
TD	✓ LAC	✓

Table 1: Duration increases due to explicit stress in the same domain. Three subjects (TA, TB, & TC) show longer lip movements in syllables with spoken stress. Two subjects (TA & TC) show longer finger tip movements in taps with emphatic stress. ($p < 0.05$)

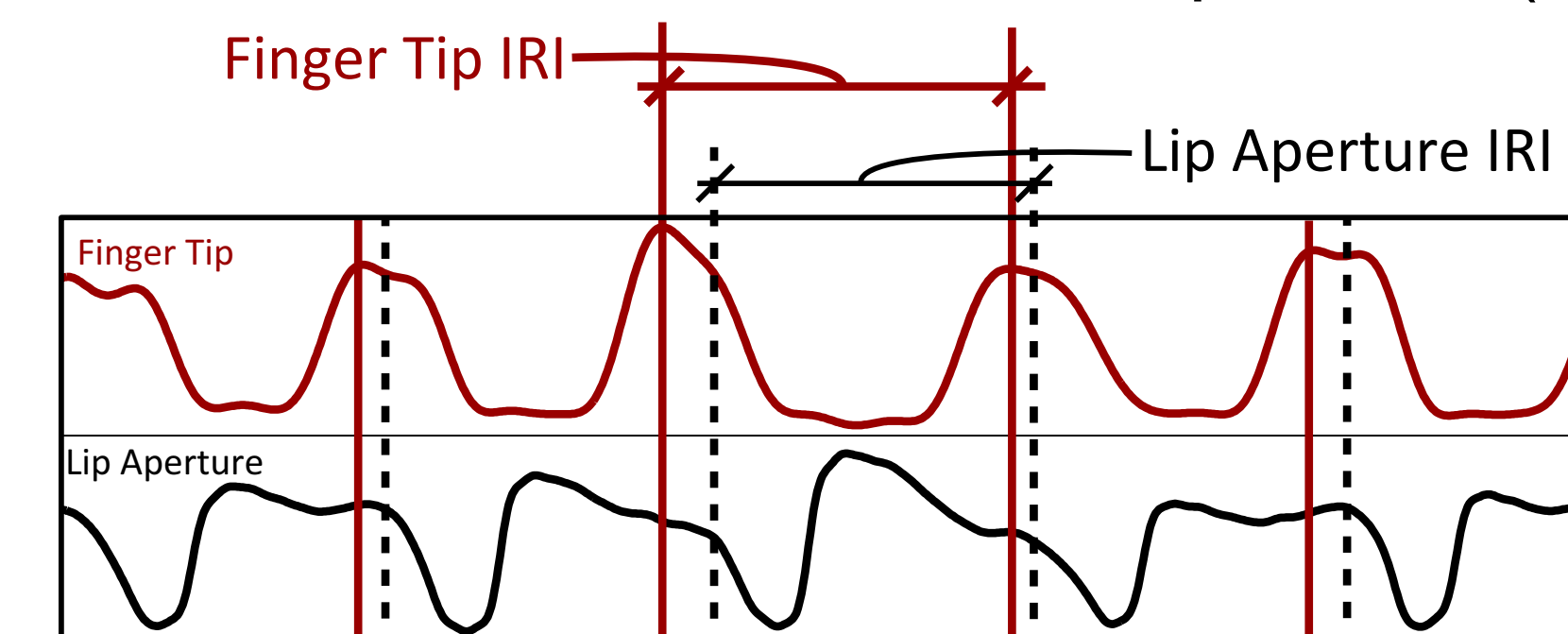
OTHER action explicitly stressed:

Subject	Spoken Stress (Effect on FT)	Tapped stress (Effect on LA)
TA	✓	✗
TB	✗	✓ LAC, LAO
TC	✗	✓ LAC
TD	✓	✓ LAC

Table 2: Duration increases due to explicit stress in the OTHER domain. Two subjects (TA & TD) show longer finger tip movements in taps synchronous with syllables with spoken stress. Three subjects (TB, TC & TD) show longer lip movements in syllables synchronous with taps given emphatic stress. ($p < 0.05$)

Results: IRI

IRI: the time between successive repetitions (Nagasaki 1987).



SAME action explicitly stressed:

Subject	Spoken Stress (Effect on LA)	Tapped stress (Effect on FT)
TA	+/-	0/0
TB	-/+	-/+
TC	-/+	0/0
TD	+/0	-/+

Table 3: Changes in IRI due to explicit stress in the same domain. In each cell, pre-boundary effects are on the left, post-boundary on the right. A "+" represents lengthening, a "-" shortening. All subjects show some change in IRI for spoken stress, and subjects TB and TD show effects for tapped stress ($p < 0.05$).

OTHER action explicitly stressed:

Subject	Spoken Stress (Effect on FT)	Tapped stress (Effect on LA)
TA	0/+	0/+
TB	-/+	-/+
TC	-/+	0/+
TD	+/+	0/+

Table 4: Changes in IRI due to explicit stress in the other domain. In each cell, pre-boundary effects are on the left, post-boundary on the right. A "+" represents lengthening, a "-" shortening. All subjects show significant post-boundary lengthening effects in both domains ($p < 0.05$).

IRI correlation in the absence of stress:

Subject	r	p
TA	0.34	< 0.001
TB	0.45	< 0.001
TC	0.44	< 0.001
TD	0.38	< 0.001

Table 3: Correlation of Inter-impulse intervals for lip and finger tip movement in the absence of stress. All subjects show a significant correlation.

Conclusions

- Subjects show temporal covariation of oral speech articulator movement and contemporaneous finger tap under emphasis of one action, **despite instructions to maintain the other action as constant and unchanging.**
- Subjects also show temporal entrainment of the two systems in the absence of any explicit stress in either domain.
- The temporal entrainment between speech and finger is as pervasive as that shown previously for magnitude.
- It may be possible to probe the control of speech phrasing and prominence through manipulation and/or observation of limb movements.