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Discrete and continuous modes in speech motor control

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Serial ordering of speech gestures

At one level, speech can be described as a sequence of discrete segments. At another level, speech is more properly described as a continuous sequence of articulatory movements and/or a continuously time-varying acoustic signal. While segments are useful for description of speech and most likely have a psychological reality, they do not occur as such in records of articulation. The reason is that coarticulation, coproduction, blending, or aggregation make the gestures associated with different segments overlap.

One method of investigating the properties of hypothetical discrete speech motor units is to disrupt ongoing articulation and examine the compensatory effects (cf., Abbs, Gracco, & Cole, 1984; Löfqvist, 1990, for reviews). From detailed examination of the compensatory characteristics it is possible to infer the underlying organization. While much information has been inferred from previous perturbation experiments, a number of limitations can be identified. First, most detailed examinations of compensatory articulatory interactions have focused on temporal and spatial changes in lip and jaw movements (Abbs & Gracco, 1984; Folkins & Abbs, 1975; Folkins & Zimmermann, 1982; Gracco & Abbs, 1985, 1988, 1989) with much less information available on compensations in other articulators (Kelso, Tuller, Vatikiotis-Bateson, & Fowler, 1984; Shaiman, 1989). Although a few studies have demonstrated magnitude changes in articulators outside the lips and/or jaw, such investigations have generally been qualitative in nature focusing on the presence or absence of a significant compensatory response rather than detailing the specific interactions (see Shaiman, 1989 for a notable exception). Recently, Munhall, Löfqvist, & Kelso (submitted) have demonstrated that lip perturbations result in laryngeal changes thereby suggesting articulatory (sensorimotor) coupling across these two systems.

A second limitation in previous perturbation studies is the almost exclusive focus on a single component in a speech movement sequence. As stated above, speech is a sequence of articulatory events. In order to understand the speech production process, it is critical to obtain information on aspects of the underlying sequencing or serial ordering of continuous vocal tract actions. To date, only two studies have focused on compensatory effects that span more than a single speech gesture (Gracco & Abbs, 1989; Saltzman, Kay, Rubin, & Kinsella-Shaw, 1991). In order to understand the underlying speech motor organization and the implementation mechanisms, more detailed investigations are required focusing on larger units of production. The following is a preliminary report of an initial investigation evaluating the distributed nature of the compensatory response to lower lip perturbation focusing on lip/jaw/laryngeal interactions. In addition to the focus on multiple components of the vocal tract, we are attempting to evaluate the local (i.e., the first perturbed gesture) and remote (the following gestures) timing/sequencing effects of speech movement disruption.

Method

The experimental procedure is illustratred in Figure 1. A subject produced the utterance 'It's a papaya again' while movements of the jaw, the lower lip, and the larynx were recorded using optoelectrical techniques. In addition, oral pressure was sensed using a catheter-tip transducer placed in the pharynx and a conventional acoustic recording was obtained. On randomized trials, a 50 gm load was applied to the lower lip via a paddle coupled to a torque motor. The rise time of the load was 12 ms and the load stayed on for 500 ms. Control trials consisted of the productions immediately preceding the perturbed trial.

Measurements were made of several kinematic, aerodynamic, and acoustic parameters. Movement onsets and offsets were defined from the first derivative of position, i.e., velocity, as points of zero velocity.

Results

Since load timing has been shown to affect the compensatory characteristics (Gracco & Abbs, 1985), the perturbed trials were grouped into two groups depending on whether the load occurred before or after the onset of lower lip raising for the closure of the first /p/. Thus, 'before' and 'after' refer to load onsets relative to the onset of lower lip raising for the first /p/. The 'before' group contained 8 tokens, while 13 tokens occurred in the 'after' group.

Predictably, the load was effectively compensated for in that peak oral pressure during the two stops did not differ between perturbed and control trials (F(1,38) = 0.0 and 0.52 for the first and second /p/, respectively, with $p>0.05$ in both cases). The kinematics of lip movements were affected by the load. As shown in Figure 2, lower lip raising displacement was greater in loaded than in unloaded trials. For the first /p/, this measure was obviously affected by load onset time, in that only loads applied before movement onset could have any effect. Thus, for the first /p/, both the effect of load, load onset time, and the interaction were significant (F(1,38) = 7.99, 19,89, and 14,05, respectively, with $p<0.05$ in all cases). For the second /p/, the effect of load and load onset time were significant (F(1,38) = 28.84, and 4.55, $p<0.05$).

Peak lower lip raising velocity for the two /p/ closures showed a similar pattern. Peak velocity was thus generally higher in perturbed than in control trials, cf., Figure 2. For the first /p/, the effect of load was not signficant (F(1,38) = 1.86, $p>0.05$), while load onset time and the interaction showed significant effects (F(1,38) = 10.67, and 5.63, $p<0.05$). For the second /p/ both load and load onset time were significant (F(1,38) = 34.3, and 5.28, $p<0.05$).

Interestingly, the duration of the lower lip raising gesture was not significantly affected by the load, or by load onset time, see Figure 2 (the F values for the first /p/ were 0.56, and 3.78, and those for the second /p/ 0.04, and 2.64, $p>0.05$). Most likely, the increased velocity of the raising gesture was responsible for this.

At the same time, it is also possible that average measures are unable to reveal significant variations due to load onset times, coarsley categorized here as 'before' and 'after' onset of lower lip movement for the first /p/. A finer grain of analysis may be required. This is suggested by Figure 3 showing plots of the duration of the lower lip raising gesture for the two stops as a function of load onset time. For the first /p/, it is evident that the duration of the gesture is longer in the load condition when the load is applied very early in relation to the onset of the lip movement. As the load onset moves closer to movement onset, the duration of the gesture decreases. For the second /p/, the same pattern is seen in the rightmost data points. In these productions, the load was applied close to the onset of the lower lip movement for the second /p/ closure.

Let us next turn to interarticulator timing. The relationship between offset of the vowel and peak glottal opening during the stop only showed a significant effect of load onset time for the second stop. Here, the interval between vowel offset and peak glottal opening was longer in the 'before' than in the 'after' condition ($F(1,38) = 31.72$, $p<0.05$).

Another way of looking at interarticulator timing is illustrated in Figure 4. This figure plots the relationship between different articulatory intervals associated with the production of the first /p/. The beginning of these intervals was always the peak glottal abduction velocity of the glottal gesture during the /ts/ in 'It's'. The endpoints of the intervals shown in Figure 4 were peak lower lip raising velocity for the first /p/ (x axis), peak abduction velocity for the first /p/ (y axis), and peak glottal opening during the first /p/ (y axis).

These plots show how different articulatory gestures change together and are coupled during speech. It is evident that the correlation between the articulatory intervals are uniformly high, above 0.8, for all conditions except when the load is applied before the onset of lower lip movement. Here, the tight temporal relationship between the movements of the lip and the larynx is disrupted. The same articulatory relationships associated with the production of the second /p/ did not show any evidence of a similar disruption due to the load.

Discussion

The present results suggest that the effects of mechanical perturbations to speech articulators are localized and related to when the perturbation occurs. That is, there does not appear to be any longlasting changes of the articulatory program as a result of the perturbation. For example, the duration of the lower lip raising movement towards /p/ closure was only affected when the load was applied just prior to movement onset. When the load was applied well in advance of movement onset, movement duration did not change because the larger displacement was associated with an increase in movement velocity. Similar findings of very small changes in movement duration in loaded trials have been reported previously by Gracco & Abbs (1988). One possible reason is that a rapid closure of the vocal tract is necessary for maintaing the acoustic characteristics of a stop consonant, in particular the rapid spectral changes that occcur at onset and release of closure. If the lip movement thus has to be made within tight temporal constraints, an increase in displacement should be accompanied by an increase in velocity. This could rationalize the positive relationship between displacement and (peak) velocity of movements that is commonly observed.

The presence of a load does not necessarily affect patterns of interarticulator timing. Thus, in the present study, the temporal relationships between lower lip and glottal movements were highly correlated even in the perturbed trials. The only exception was lip-laryngeal phasing for the first /p/ in the 'before' condition. Also this finding is consistent with the results presented by Gracco & Abbs (1988) for lip-lip, and lip-jaw timing in the presence of a load.

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References

Abbs, J. & Gracco, V. L. (1984) Control of complex motor gestures: Orofacial muscle response to load perturbations of the lips during speech. *Journal of Neurophysiology*, 51: 705-723.

Abbs, J., Gracco, V. L., & Cole, K. (1984) Control of multimovement coordination: Sensorimotor mechanisms in speech motor programming. *Journal of Motor Behavior*, 16: 195-232.

Folkins, J. & Abbs, J. (1975) Lip and jaw motor control during speech: Responses to resistive loading of the jaw. *Journal of Speech and Hearing Research*, 18: 207-220.

Folkins, J. & Zimmermann, G. (1982) Lip and jaw interaction during speech: Responses to perturbation of lower-lip movement prior to bilabial closure. *Journal of the Acoustical Society of America*, 71: 1225-1233.

Gracco, V. L. & Abbs, J. (1985) Dynamic control of the perioral system during speech: Kinematic analyses of autogenic and non-autogenic sensorimotor processes. *Journal of Neurophysiology*, 54: 418-432.

Gracco, V. L., & Abbs, J. (1988) Central patterning of speech movements. *Experimental Brain Research*, 71: 515-526.

Gracco, V. L. & Abbs, J. (1989) Sensorimotor characteristics of speech motor sequences. *Experimental Brain Research*, 75: 586-598.

Kelso, J. A. S., Tuller, B., Vatikiotis-Bateson, E., & Fowler, C. (1984) Functionally specific articulatory cooperation following jaw perturbations during speech: Evidence for coordinative structures. *Journal of Experimental Psychology: Human Perception and Performance*, 10: 812-832.

Löfqvist, A. (1990) Speech as audible gestures. In W. Hardcastle & A. Marchal (Eds.) *Speech Production and Speech Modelling*, pp. 289-322. Dordrecht: Kluwer.

Munhall, K. G., Löfqvist, A., & Kelso, J. A. S. (submitted) Lip-larynx coordination in speech: A perturbation study. Submitted to *Journal of the Acoustical Society of America*..

Saltzman, E., Kay, B., Rubin, P. E., & Kinsella-Shaw, J. (1991) Dynamics of intergestural timing. Paper presented at the conference *Current Phonetic Research Paradigms: Implications for Speech Motor Control*, Stockholm.

Shaiman, S. (1989) Kinematic and electromyographic responses to perturbation of the jaw. *Journal of the Acoustical Society of America*, 86: 78-88.

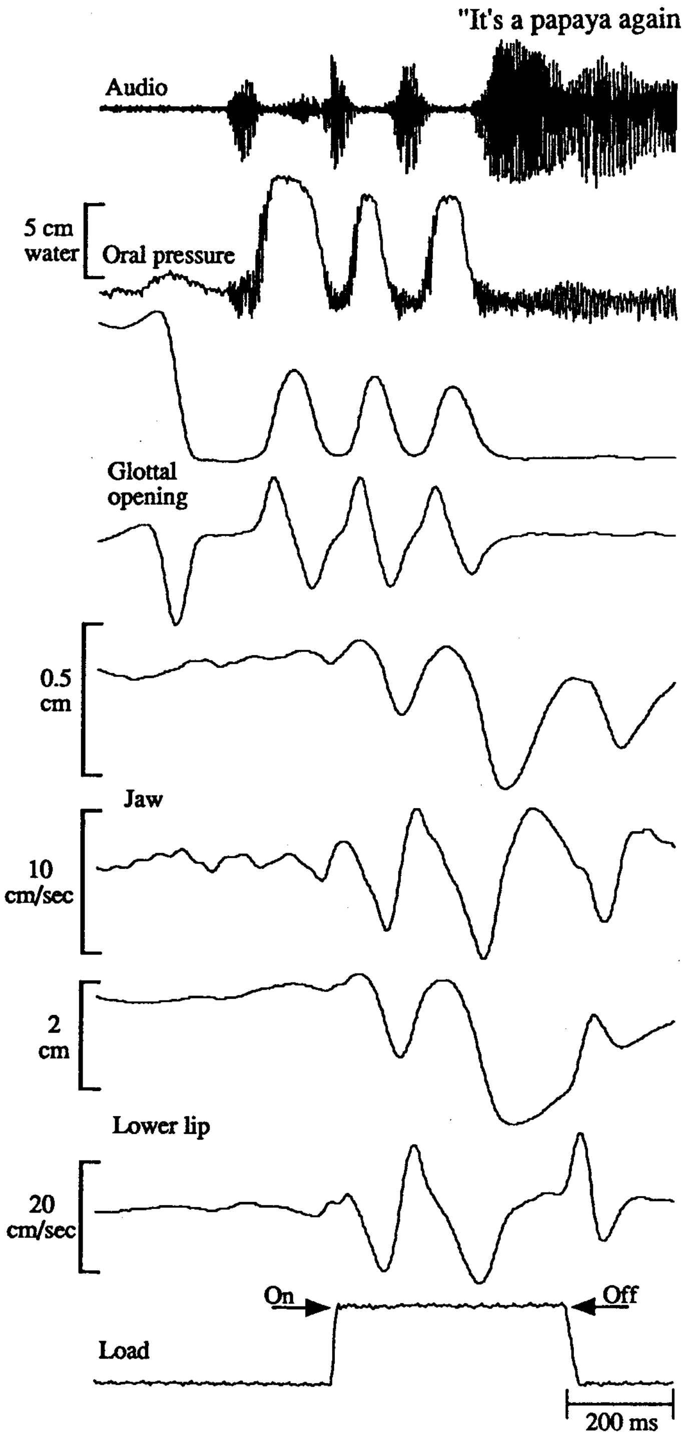

Figure 1. A perturbed production of 'It's a papaya again'. For glottal opening, jaw, and lower lip, both displacement and velocity are shown.

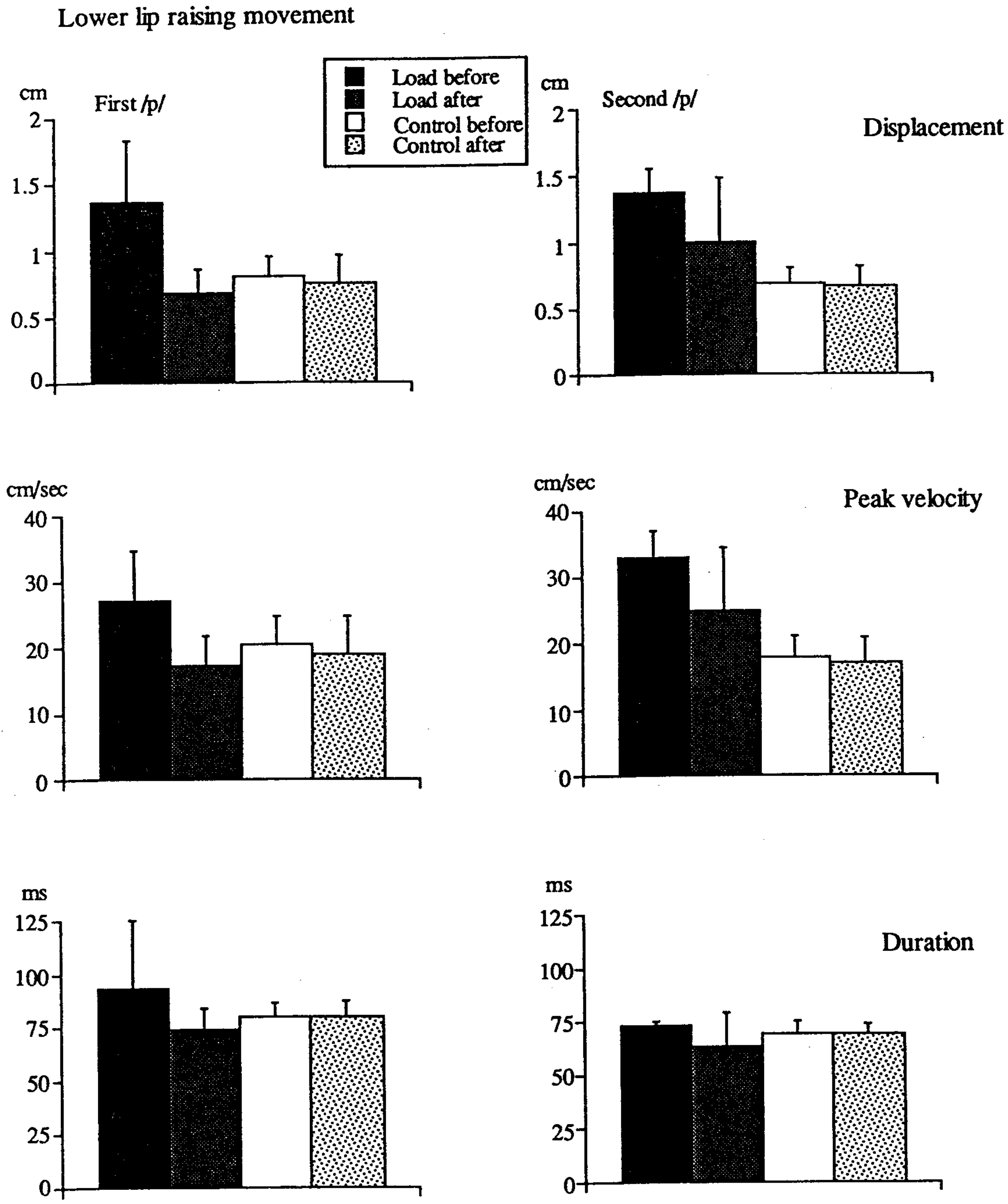

Figure 2. Displacement, peak velocity, and duration of lower lip raising movement for first (left) and second (right) /p/ in 'papaya' during load and control trials.

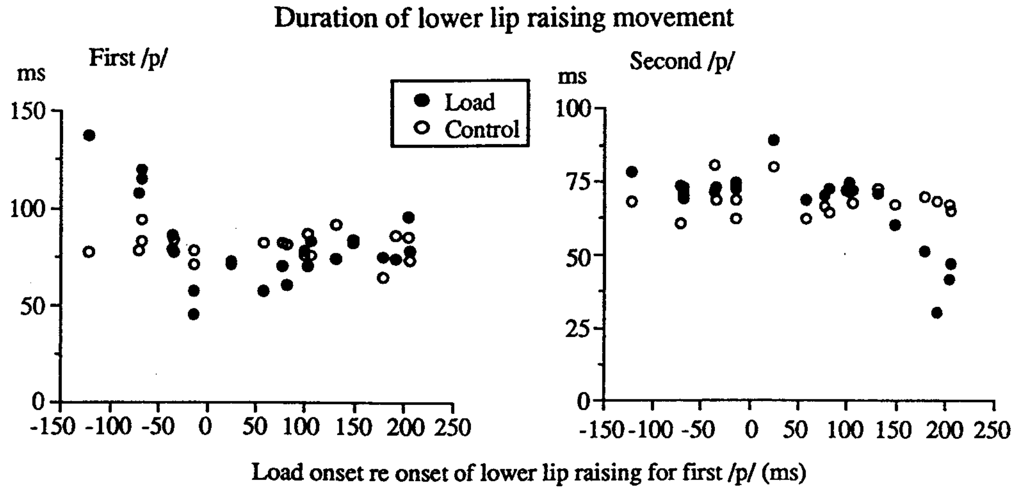

Figure 3. Duration of lower lip raising movement for first (left) and second (right) /p/ in 'papaya' in load and control trials. The x-axis plots the onset of the load relative to onset of lower lip raising movement for the first /p/.

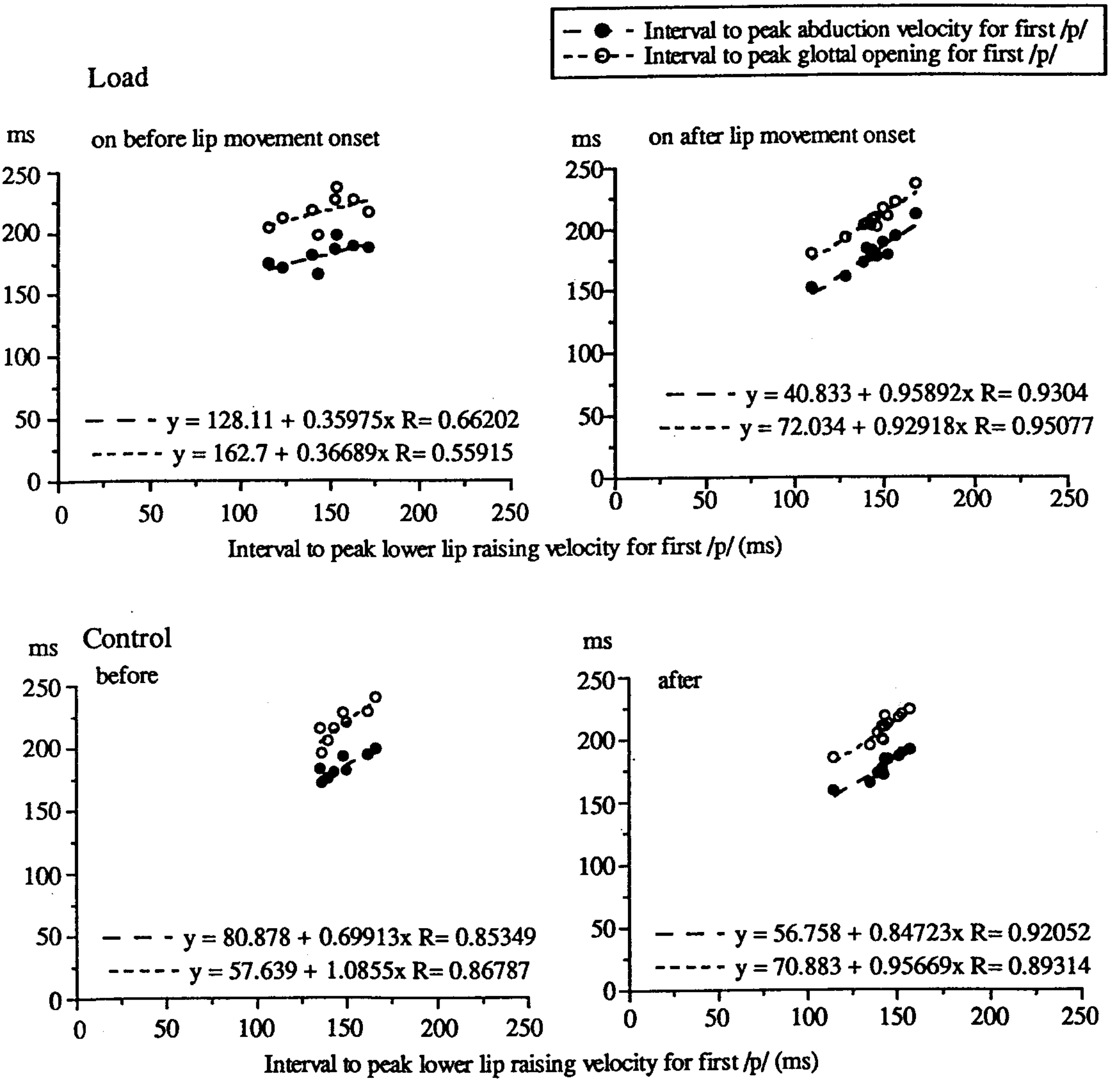

Figure 4. Relationships between oral and laryngeal articulatory intervals in the production of the first /p/ in 'papaya' for load and control trials. The interval to peak lower lip raising velocity is plotted along the x-axis; the y-axis plots the intervals to peak glottal abduction velocity and peak glottal opening.