SPATIOTEMPORAL STABILITY OF THE TONGUE-JAW AND LIP-JAW COMPLEX: COMPARISONS ACROSS SESSIONS

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ABSTRACT
The search for invariant motor control schemes most often is based upon articulatory data collected from a single session and within a single speech rate. Thus, we know little about the stability of gestural organization and coordination across relatively long periods of time. Articulatory data were collected over multiple sessions and rates. Only motor equivalence covariability, compared to a number of spatial and temporal measures, was stable across sessions for all subjects.

INTRODUCTION
Certain observed characteristics of the motor system, such as motor equivalence covariability, have lead to the idea that there is an underlying invariance in the motor control scheme despite the observed surface variations in performance. In particular, the notion of coordinative structures in dynamical models of speech production, and in dynamical models of movement in general, is based on the idea of underlying invariant motor control schemes to meet a specified task [1,2]. However, and in spite of the decades-long search for the so-called invariant characteristics of normal speech production, the majority of the often cited motor characteristics of speech [e.g., 3] are much more variable in repeated-trial tasks than they are invariant.

Most often the search for invariant control schemes focuses on data collected from a single session and within a single speech rate condition. The overall purpose of these ongoing experiments is to explore further the saliency of certain presumed invariant motor characteristics of speech, and by extension, the notion of coordinative structures, by comparing certain spatiotemporal characteristics of tongue-jaw and lip-jaw movements for stops and fricatives across multiple sessions and across speech rate.

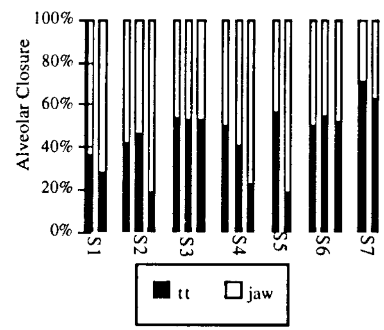
For the purposes of the experiments reported here, motor coordination and organization are not synonymous. First, the primary criterion that a speech motor characteristic must meet in order to reflect a well-coordinated speech motor gesture is in its relative stability. Second, the organization of a speech motor gesture refers to the contribution of the components of an articulatory synergy toward the specified task, and does not in itself invoke assumptions about coordination.

METHODS
The movements of the tongue blade, lips, and jaw were transduced by electromagnetic midsagittal articulography (EMMA). A single session included twenty perceptually fluent repetitions of the target words /pap/, /tat/, and /sas/ imbedded in the Dutch carrier phrase "Zij zei CVC alveer." The 60 phrases were blocked by rate and produced first at a normal speech rate, than again at a fast rate, and finally at a slow rate. Sessions were repeated three times, and the interval between sessions was about two weeks. Thus, approximately 540 utterances (3 words X 20 repetitions X 3 rates X 3 sessions) per subject were collected. Seven native Dutch talkers completed either 2 or 3 sessions. Only data associated with closure movements for syllable initial /p/ and /t/ during the normal rate condition are discussed here. Considerable software development, calibration procedures, and hardware modifications were made to the Carstens EMMA system used here [4,5].

RESULTS
1. Spatial Organization and Coordination.
General trends in the organizational stability for /t/ closure are demonstrated in Figure 1, which shows the normalized vertical displacement for /t/ closure across two or three sessions for seven control subjects. While organizational patterns differ across subjects, for example, Subject 1 achieves /t/ closure primarily by jaw displacement while Subject 7 achieves closure primarily by tongue

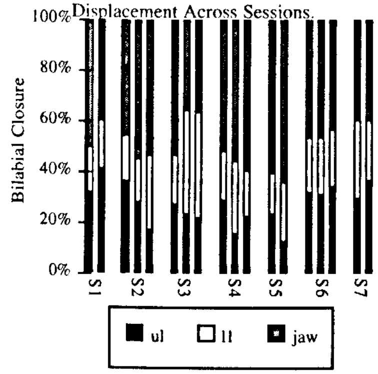
displacement, the relative displacement patterns within subjects are generally stable across sessions for subjects 1, 3, 6, and 7. In the remaining three subjects, only Subject 5 shows a reversal in the primary articulator for closure. That is, /t/ closure is achieved primarily by tongue displacement in session 1 but primarily by jaw displacement in session 2. Subjects 2 and 4 achieve closure primarily by tongue displacement, although the relative contribution of the tongue and the jaw for closure varies considerably across sessions.

Figure 1. /t/ Closure. Normalized Vertical Displacement Across Sessions.



General trends in the organizational stability for /p/ closure are demonstrated in Figure 2.

Figure 2. /p/ Closure. Normalized Vertical Displacement Across Sessions.



As in the case of /t/ closure, organizational patterns differ across subjects. For example, Subject 5 achieves /p/ closure primarily by jaw displacement and secondarily by lower lip displacement with little contribution of the upper lip. On the other hand, Subject 6 achieves closure primarily by jaw displacement, secondarily by upper lip displacement, with little lower lip displacement. However, the relative displacement patterns within subjects are generally stable across sessions for 4 of the 7 subjects.

Details of the closure gestures for Subject 2, the only subject who demonstrated unstable organizational patterns for both /t/ and /p/ closure, are shown in Figures 3 and 4.

Figure 3. /p/ Closure. Subject 2. Vertical Displacement Across Sessions.

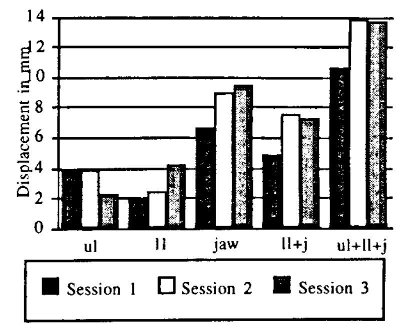
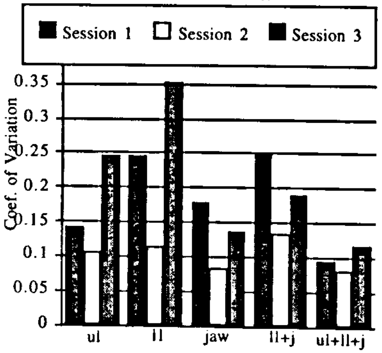


Figure 3 shows the average absolute vertical displacements of the upper lip (ul), lower lip (ll), and jaw for /p/ closure across three sessions. Note that this subject presents different closure strategies across sessions. For example, upper lip displacement is twice as great as lower lip displacement in sessions 1 and 2 but half as great in session 3. Also note that differences in average total displacement across the three sessions is about 3.5 mm. The peak velocity profiles generally correspond to the displacement profiles.

Figure 4 shows that although the control strategies vary across sessions, the lips and jaw demonstrate motor equivalence covariability and thus are well coordinated across sessions for /p/ closure. The figure shows that the variability of the labial gesture, that is, the combined ul+ll+j displacement, is less than the variabilities associated with either the upper lip, lower lip, or jaw signals for each of the three sessions. Thus, Subject 2, who is the least stable of the seven subjects for both /t/ and /p/ closure in regard to both the relative organizational patterns shown in Figures 1 and 2 and in the absolute displacements shown in Figure 3, demonstrates consistent motor equivalence covariability. That is, the gestural organization varies but gestural coordination remains stable, a result that is observed in all of the subjects regardless of the idiosyncratic organizational patterns that they exhibit.

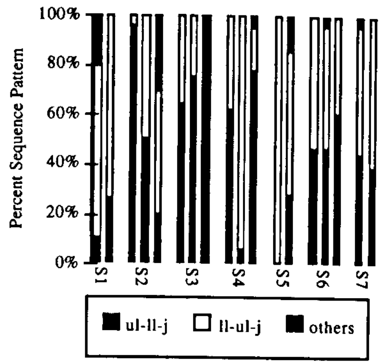
Figure 4. /p/ Closure. Subject 2. Coefficient of Variation Across Sessions.



2. Temporal Organization and Coordination.

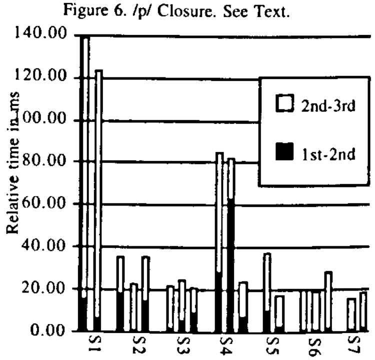
Figure 5 shows the within and across session relative distribution of the upper lip, lower lip, and jaw sequence patterns for /p/ closure for seven subjects. The closed portions of the bars represent the upper lip, lower lip, and jaw sequence, the open portions represent the lower lip, upper lip, and jaw sequence, and the hatched portions represent all others. By far, the predominant sequences are those in which lip movement occurs first and jaw movement occurs last. First, the figure shows that either lip lead sequence is equally likely to occur. For example, Subject 1 prefers the lower lip lead sequence while Subject 3 prefers the upper lip lead sequence. Second, the figure shows that some subjects, for example Subject 6, show no clear preference for either lip lead sequence. Third, the figure shows that two of the subjects, 2 and 4, show a clear reversal in the lip lead sequence across sessions.

Figure 5. /p/ Closure Across Sessions and Subjects. Relative Distribution of Sequences re Peak Velocity.



The temporal ordering of the movements of the speech articulators was thought to represent a motor invariant in the temporal domain in that an invariant upper lip, lower lip, and jaw sequence for bilabial closure was reported for a large group of control subjects [6]. However, recent research suggests that the initial conclusion in regard to invariance may have been over generalized [7]. The data reported here support the recent findings and, further, demonstrate that temporal ordering is quite unstable across sessions for some subjects.

Figure 6. /p/ Closure. See Text.



One of the reasons that the sequence pattern is not stable across time is that it does not reflect interarticulator relative time. Subjects who demonstrate tight coupling between lip movements, for example, would have a higher probability of producing both lip-lead sequences compared to subjects who demonstrate longer relative timing of the lip movements. This is demonstrated in Figure 6, which shows the lip relative time and the lagging lip to jaw relative time for the average sequences per session. (The relative time profiles that correspond to each of the sequences are similar to each other, and they are similar to the relative time profiles for the session average sequences shown in Figure 6.) Note that the relative time for lip movements in the case of Subjects 6 and 7 is less than five ms. Figure 5 shows that these subjects demonstrate nearly equal probability of producing either lip-lead sequences. Thus, an invariancy criterion based on consistent sequence patterns would exclude subjects 6 and 7 whereas a criterion based on tight interarticulator timing would include the same subjects.

DISCUSSION

The data shown in Figures 5 and 6 demonstrate that for some subjects neither temporal ordering nor relative time are stable across sessions and thus do not represent invariant speech motor characteristics. Further, it appears that subjects who are relatively unstable across sessions in regard to these two temporal measures are also relatively unstable in regard to displacement characteristics. For example, Subject 2 achieves closure with varying spatial strategies (Figures 1-4) and with varying temporal strategies (Figures 5-6) across sessions. Only motor equivalence covariability is stable across sessions for all subjects, that is, even in the case of unstable spatial and temporal organizational characteristics such as demonstrated by Subject 2.

A conclusion that could be drawn from a stable coordination index (motor equivalence covariability) regardless of the stability of the displacement pattern, temporal order, or interarticulator relative timing is that the spatial and temporal organization of functionally linked articulators is secondary to gestural specification, that is, bilabial closure in this example. This is precisely what would be predicted from a task dynamic point of view; that the spatial and temporal organizational characteristics of the individual articulators that comprise an articulatory complex represent the natural consequence of gestural coordination and therefore would not demonstrate stability across sessions.

REFERENCES

[1] Saltzman, E. (1991). "The task dynamic model in speech production." In H.F.M. Peters, W. Hulstijn, and C.W. starkweather (Eds). *Speech motor control and stuttering* (pp. 37-52). Amsterdam: Excerpta Medica.
[2] Saltzman, E., & Munhall, K. (1989). "A dynamical approach to gestural patterning in speech production. " *Ecological Psychology,* 1, 333-382.
[3] Gracco, V.L. (1994). "Some organizational characteristics of speech movement control." *Journal of Speech and Hearing Research,* 37, 4-27.
[4] Alfonso, P.J., Neely, J.R., van Lieshout, P.H., Hulstijn, W., & Peters, H.F. (1993). "Calibration, Validation, and Hardware-Software Modifications to the Carstens EMMA System.." *Proceedings of the ACCOR Workshop on Electromagnetic Articulography in Phonetic Research.,* Munich, Germany. Also in *Haskins Laboratories Status Report of Speech Research, SR-114,* 101-112.
[5] Van Lieshout, P.H.H.M., Alfonso, P.J, Hulstijn,W., & Peters, H.F.M. (1994). "Electromagnetic Midsagittal Articulography (EMMA)." In F. J. Maarse, A.E. Akkerman, A.N. Brand, L.J.M. Mulder, and M.J. van der Stelt (Eds.), *Computers in Psychology 5: Applications, Methods, and Instrumentation.* (pp. 62-76). Lisse, The Netherlands: Swets & Zeitlinger.
[6] Gracco, V.L. and Abbs, J.H. (1986). "Variant and invariant characteristics of speech movements. "*Experimental Brain Research, 65,* 156-166.
[7] Van Lieshout, P.H.H.M., Alfonso, P.J., Hulstijn, W., & Peters, H.F.M. (1993). "Significance of relative-timing towards an interpretation of articulatory sequencing." *ASHA, 35-10.,* 191.