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THE ORGANIZATION OF SUPRALARYNGEAL ARTICULATION IN STUTTERERS' FLUENT SPEECH PRODUCTION: A SECOND REPORT

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INTRODUCTION

The purpose of the experiment reported here is to determine the extent to which the magnitude of relatively invariant spatial characteristics of normal speech dynamics approximates corresponding characteristics of stutterers' perceptually fluent speech. Since speech articulatory gestures produced by normal speakers are inherently associated with varying degrees of within and across subject variability, across subject and group comparisons on the basis of relatively stable or "invariant" characteristics of speech dynamics is an important distinction. The underlying assumption is that certain articulatory gestures are relatively stable across varying rate and stress conditions and in repeated-trial tasks, and that these invariant characteristics of speech best reflect speech motor control processes (e.g. Tuller, Harris, Kelso1); Kelso, V.-Bateson, Saltzman, and Kay2); Gracco and Abbs3)). This is a particularly important distinction to make in regards to experiments designed to compare speech motor control in the fluent speech of stutterers with the speech of normal speakers because of the ubiquitous observation of "considerable" variability in seemingly every aspect of stutterers' speech accessible to measurement. Accordingly, the comparisons of speech dynamics between the groups reported here are based on a spatial characteristic of speech movement that has been shown to be relatively stable in repeated-trial tasks, namely the patterns of trial-to-trial variability for individual and combined signals representing the displacement and velocity of supralaryngeal speech structures3).

In a preliminary report of the kinematics associated with [s] and [t] closure in fluently produced nonsense syllables, Alfonso, et. al.4) observed that the trial-to-trial variability of tongue, lip, and jaw displacement was much greater for a severe stutterer in comparison to a control subject. They also reported that the organization of lip, tongue, and jaw displacement in [s] and [t] closure was different between the two subjects. Based on analysis of the partial data set, a hypothesis was developed that stutterers control the speech motor system in a fashion that is different from normal speakers even during speech that is perceptually fluent. Specifically, the hypothesis

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predicts: 1) that in repeated-trial tasks the movements of individual structures, tongue displacement for example, would be more variable in stutterers' fluent speech compared to control subjects' fluent speech, and 2) that vocal-tract gesture variability, represented by the combined tongue displacement and jaw displacement signals for example, would be less variable than either the individual tongue or the individual jaw displacement signal for control subjects but not for stutterers. The hypothesis predicts that stutterers, compared to control subjects, are less able to relationally control individual supralaryngeal structures comprising a vocal-tract gesture; rather, structures comprising a vocal-tract gesture are controlled in a more independent fashion than observed in control subjects. Multiarticulate speech gestures organized in such a way would yield vocal-tract gesture variability comparable to, but not less than, the magnitudes of the variabilities associated with the individual structures that comprise the vocal-tract gesture. On the other hand, speakers who demonstrate covariability between members of a supralaryngeal complex would generate vocal-tract variability of less magnitude than either structure of the complex.

This second report tests the above hypothesis by analyses of the complete set of spatial data from three subjects representing obstruent closure and release gestures in fluent productions of /eCeCe/ where /C/ represents /t/, /s/, or /n/ in both positions. Data currently available on the control of supralaryngeal movement are predominantly restricted to lip and jaw movements since the movements of these structures are relatively easy to capture. This study extends previous work in the control of multiarticulate movement by both normal speakers and stutterers by examining relatively invariant characteristics of tongue and jaw articulation in the fluent speech of two stutterers and a control subject. The experiment will help determine whether the stutterers' speech motor system exhibits generalized spatio-temporal abnormalities regardless of the perceived fluency, or whether, alternatively, it behaves normally except during moments of dysfluency. Lastly, Figures 7 and 5 of this report replace Figures 3 and 5, respectively, of Alfonso, et. al.4) which were produced in error.

METHODS

The x-ray microbeam installation at the University of Tokyo was used to track the movements of lead pellets attached to the jaw, lower lip, tongue blade, and velum. In addition, we used a Respitrace inductance plethysmograph to capture movements of the thorax and abdomen, and a Syncrovoice electroglottograph to infer movements of the vocal folds. Complete details of the procedures are given in Alfonso, et. al.4) Three adult males served as subjects: a severe stutterer, a mild-moderate stutterer, and a control subject. Subjects were instructed to respond to a light by producing the vowel /e/ as quickly as possible and sustaining the vowel until presentation of a second light. At that time, subjects were required to produce /tete/, /sese/, or /nene/. The interval between the first and second light was systematically varied between 500 to 1500 ms. Subjects produced about 12 fluent productions of each of the nonsense syllables. Fluency and stuttering severity criteria used in this experiment have been reported elsewhere5),6).

Figure 1 shows tongue blade and jaw pellet trajectories and the acoustic record associated with a single production of /esese/ by the control subject. Jaw displacement was digitally subtracted from the lower lip and tongue blade trajectories yielding individual tongue blade, lip, jaw, and combined tongue-jaw and lip-jaw signals. Displacement onsets and offsets were identified by the derived velocity zero-crossing. The discussion that follows is limited to analyses of tongue blade, jaw, and combined tongue-jaw vertical movements for initial consonant closure and final consonant release.

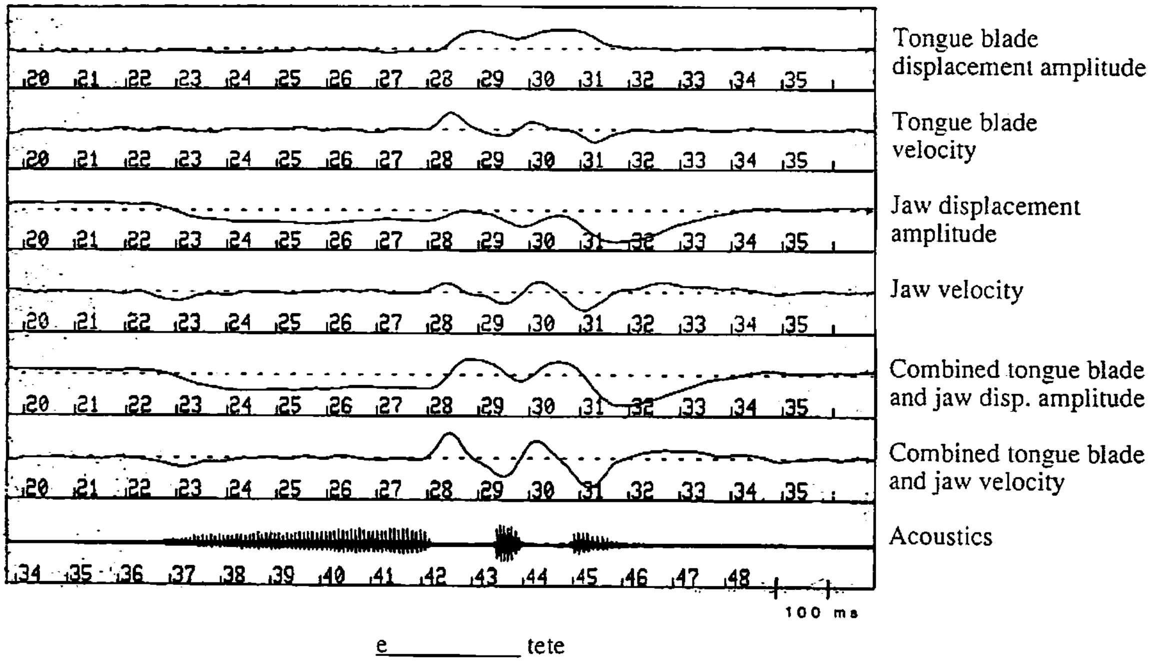

Fig. 1 Tongue blade, jaw, and combined tongue-jaw vertical displacement amplitude and derived velocity trajectories for a single production of /etete/ by the control subject.

RESULTS

Figure 2 shows peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [s] closure for 12 productions of /esese/ by the control subject. Figure 3 shows the same parameters during initial [t] closure for 11 productions of /etete/ by the same subject. Positive displacement and velocity values represent upward movements while corresponding negative values represent downward movements of the lip, jaw, and tongue.

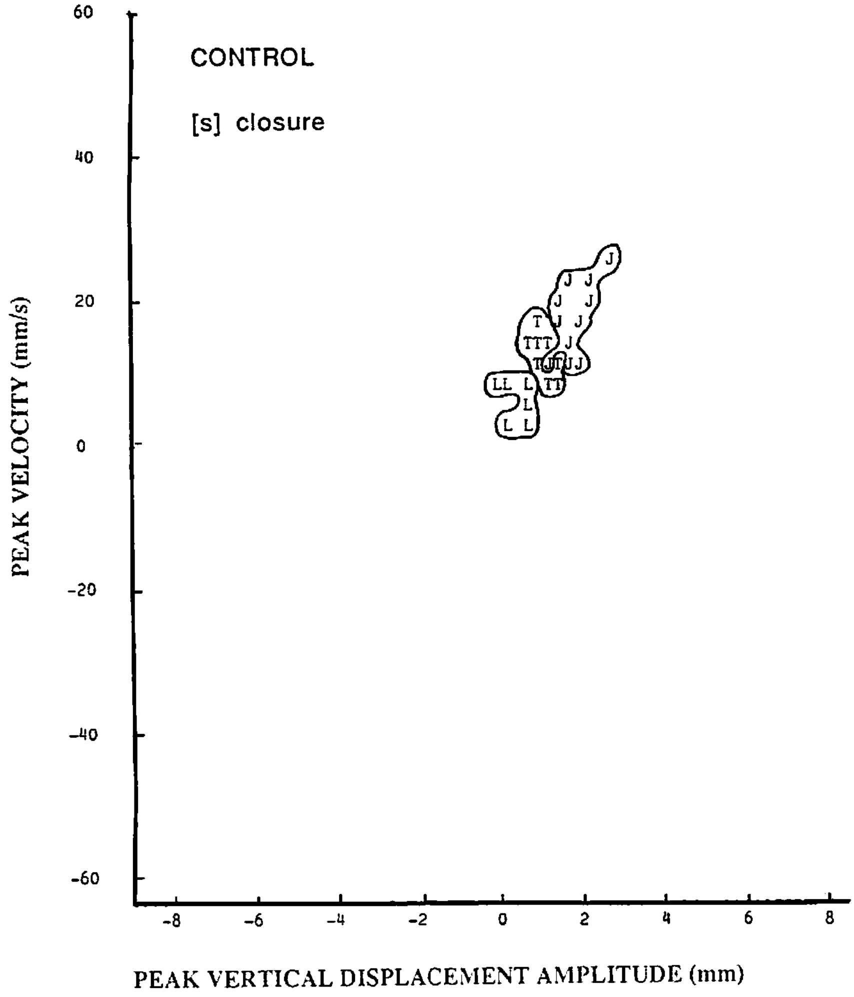

Fig. 2 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [s] closure for 12 productions of /esese/ by the control subject. Jaw displacement digitally subtracted from tongue and lip displacement.

For the sake of clarity, we have enclosed the data points associated with the movement of each structure within solid lines. First, note that the same general relationship between displacement amplitude and peak velocity previously reported for limb movements and lip-jaw movements holds for these data as well[2]. That is, peak velocity increases as displacement amplitude increases. Second, note that the control subject achieves closure by complimentary activity of jaw and tongue blade. For example, in the 12 tokens of /esese/ shown in Figure 2, average jaw vertical displacement is approximately 2 mm and average tongue vertical displacement is approximately 1 mm. Finally, note that displacement and velocity dispersions for each of the structures are relatively small.

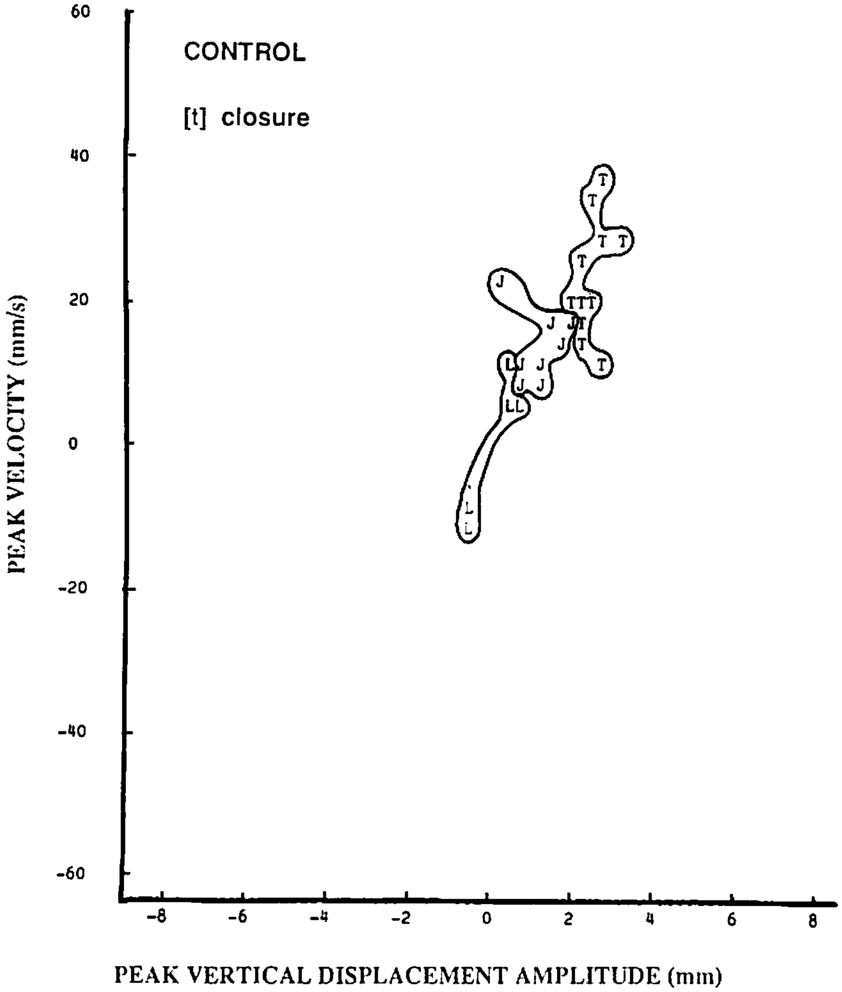

Fig. 3 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [t] closure for 11 productions of /etete/ by the control subject. Jaw displacement digitally subtracted from tongue and lip displacement.

The next two figures show the same movement parameters for the mild-moderate stutterer's initial [s] closure gestures for 13 productions of /esese/ (Figure 4) and initial [t] closure gestures for 11 productions of /etete/ (Figure 5). Note, first, that the peak velocity to peak displacement amplitude ratios for this subject are similar to those of the control subject. However, the figures demonstrate that the organization of the closures is different from that of the control subject. Recall

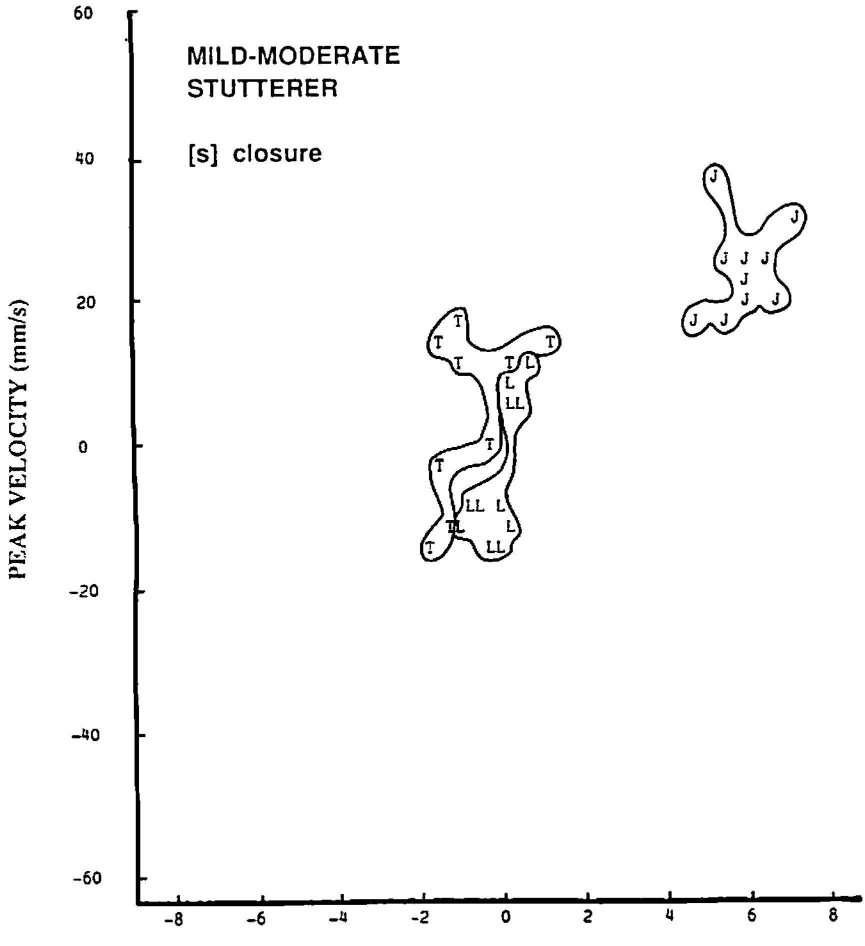

Fig. 4 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [s] closure for 13 productions of /esese/ by the mild-moderate stutterer. Jaw displacement digitally subtracted from tongue and lip displacement.

that the control subject achieves closure by complimentary activity of the jaw and tongue. The mild-moderate stutterer achieves closure by jaw elevation alone. For example, the average jaw elevation for the 13 [s] closures shown in Figure 4 is about 6 mm, while the average tongue displacement is about 1 mm in the opposite direction. Finally, note that trial-to-trial variability for both peak displacement amplitude and peak velocity for each of the structures appears to be greater for the mild-moderate stutterer than for the control subject.

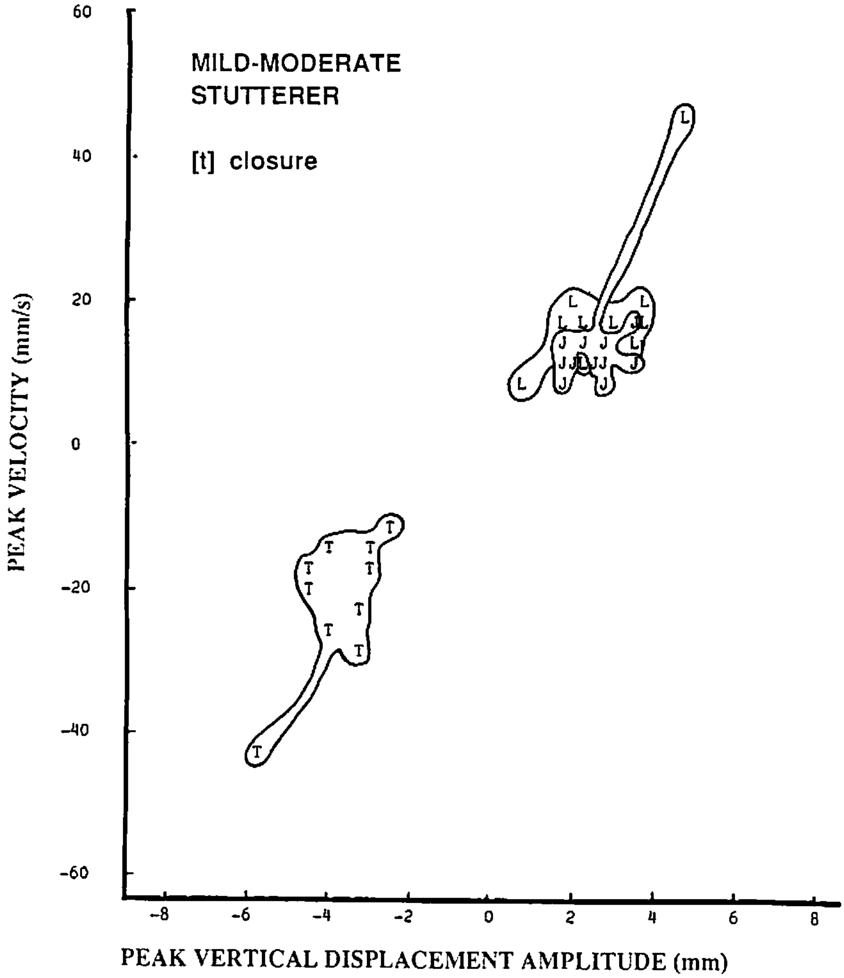

Fig. 5 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [t] closure for 11 productions of /etete/ by the mild-moderate stutterer. Jaw displacement digitally subtracted from tongue and lip displacement.

Figures 6 and 7 demonstrate that the same three relationships are observed in the severe stutterer's data. In fact, the relationships hold for the complete data set, that is, initial consonant closure and final consonant release in /esese/, /etete/, and /enene/. First, the stutterers and the control subject are similar with respect to the dynamics of individual tongue and jaw movements as reflected by peak velocity to peak displacement amplitude ratios. The correlations for peak displacement amplitude and peak velocity for the complete data set are .89, .94, and .95 for the control, mild-moderate, and severe stutterers, respectively. Second, the stutterers differ from the control subject with respect to the efficiency and flexibility in the organization of the closure and release gestures. The control subject achieves closure and release gestures by complimentary movements of the tongue and jaw, the relative contributions of each structure toward the vocal-tract gesture being

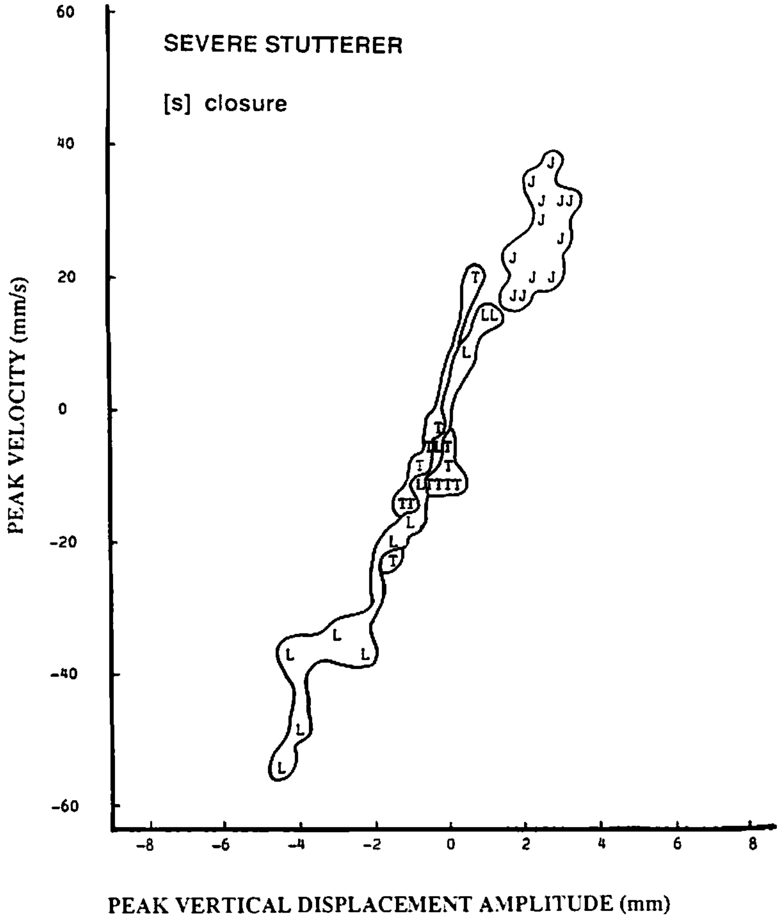

Fig. 6 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [s] closure for 12 productions of /esese/ by the severe stutterer. Jaw displacement digitally subtracted from tongue and lip displacement.

phonetically dependent. For example, the control subject shows a different tongue-jaw synergy for [s] versus [t] closure. For [s], the jaw contributes primarily to elevation and the tongue contributes primarily to shape. For [t], the tongue contributes primarily to elevation. The stutterers' organization of closure or release gestures does not reflect this flexibility. Rather, the stutterers achieve closure and release in all phonetic conditions primarily by jaw displacement with little, and occasionally paradoxical, tongue displacement. Finally, the stutterers demonstrate greater trial-to-trial variability than the control subject in tongue, jaw, and combined tongue-jaw peak displacement amplitude and peak velocity. The variability is greatest for the severe stutterer and least for the control subject. In fact, the [s] closure data shown in Figures 2, 4, and 6 represent the phonetic condition in which combined tongue-jaw variability of the control subject is least dissimilar to that of the two stutterers.

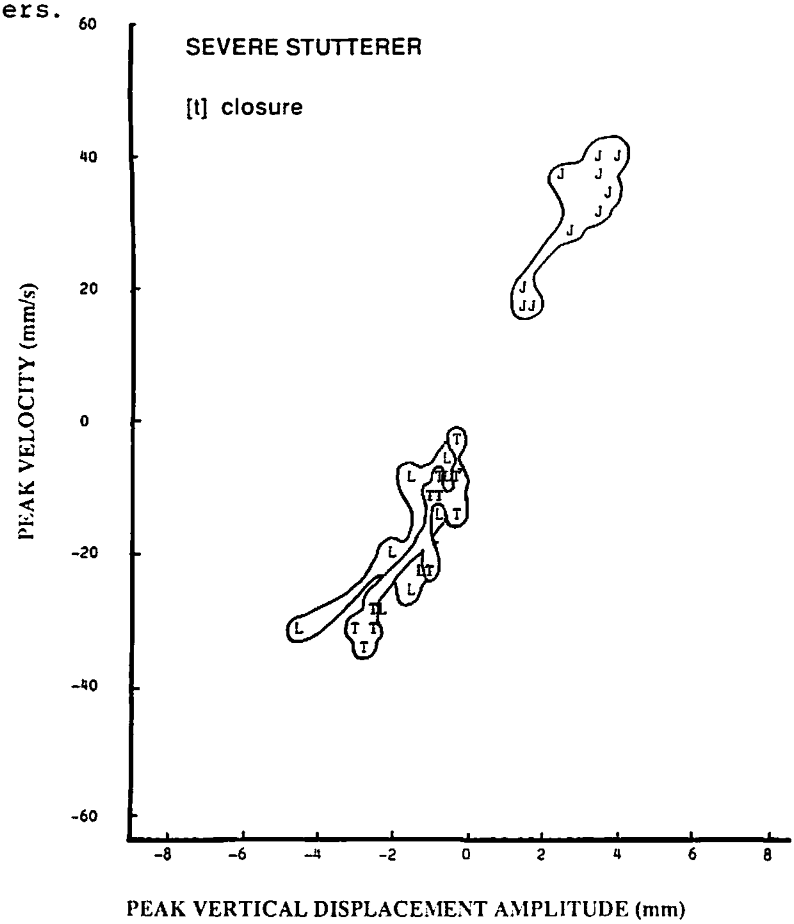

Fig. 7 Peak vertical displacement amplitude by derived peak velocity for lower lip (L), tongue blade (T), and jaw (J) movements during initial [t] closure for 11 productions of /etete/ by the severe stutterer. Jaw displacement digitally subtracted from tongue and lip displacement.

The group difference in trial-to-trial peak displacement amplitude variability is clearly shown in Figure 8. We use the coefficient of variation (CV) here. The CV represents the ratio of the standard deviation and the mean, and thus permits a comparison of displacement variability among different speech structures despite differences in absolute displacement for each of the structures. The average CV shown in Figure 8 represents the weighted average of the CV's for initial consonant closure and final consonant release in /etete/ and /esese/. For the control subject and the severe stutterer, it also includes initial consonant closure and final consonant release in /enene/. The total number of measurements made for tongue, jaw and combined tongue-jaw displacements are also shown. Figure 8 shows that the CV for individual tongue, jaw and combined tongue-jaw peak displacement is greater for the stutterers than for the control subject, and that the variability is greater for the severe stutterer compared to the mild-moderate stutterer. The figure also shows that for the control subject, the variability

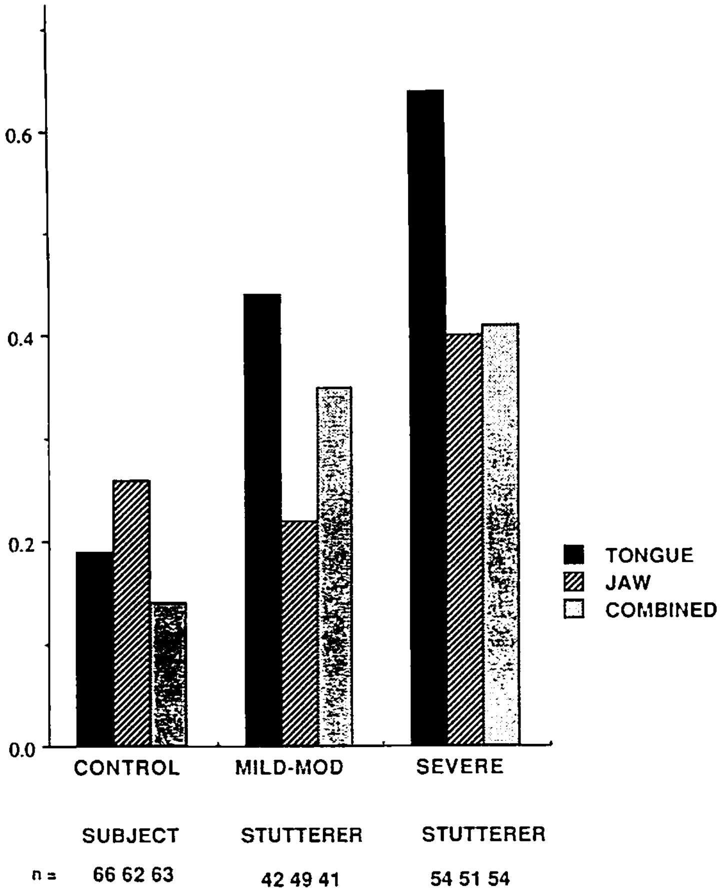

Fig. 8 Weighted average coefficients of variation for tongue blade, jaw, and combined tongue-jaw peak vertical displacement amplitude.

associated with combined tongue-jaw displacement is less than the variability associated with individual tongue blade and jaw displacement. Notice, however, that the relationship between the smaller combined signal variability compared to the larger individual signal variability is not observed in the stutterers' data.

Figure 9 shows the CV for the first derivative of the displacement data shown in Figure 8. Notice that the patterns of CV for peak velocity are in good agreement with the CV for peak displacement amplitude. Again, for the stutterers, the CV is greater than for the control subject and, more importantly, the variability of the combined tongue-jaw signal is not less than that of the individual tongue or jaw signals. The magnitudes and relative patterns of CV for both peak displacement amplitude and peak velocity for the control subject are similar to that reported by Gracco and Abbs3) for a larger group of normal subjects.

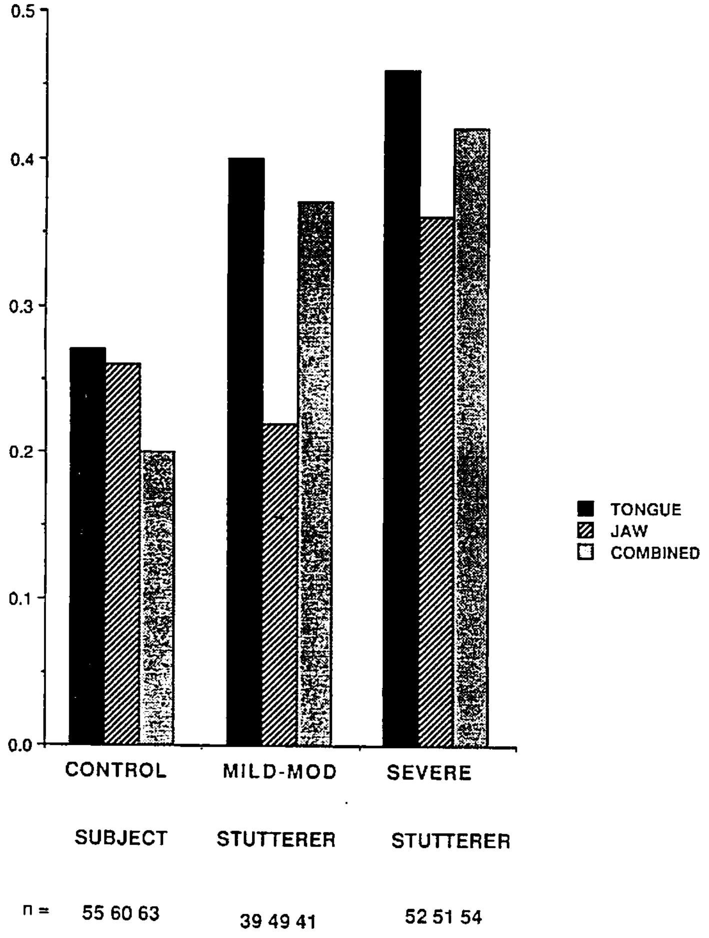

Fig. 9 Weighted average coefficients of variation for tongue blade, jaw, and combined tongue-jaw derived peak velocity.

DISCUSSION

The covariability in the individual tongue and jaw displacement data for the control subject supports the notion that the speech motor plan in normal speakers is specified in terms of relational interactions between structures of a supralaryngeal complex so that combined tongue-jaw movements, for example, result in relatively invariant vocal-tract gestures. The lack of covariability in individual tongue and jaw displacement and the dominance of a single structure of a supralaryngeal complex to achieve a vocal-tract gesture suggest that stutterers' control of the speech motor system lacks the flexibility and efficiency to meet invariant multiarticulate goals.

In summary, the hypothesis initially developed by Alfonso, et. al.4) is supported by the data reported here. The results indicate that individual tongue and jaw movements during the fluent speech of stutterers and control subjects are similar in regard to the relationship between peak displacement amplitude and peak velocity. For both groups, velocity increases as displacement amplitude increases. This relationship is characteristic of movement in general and has been observed in speech and non-speech behaviors2),7). The more interesting comparison, with respect to speech motor control, is the relationship between tongue and jaw movement. In this respect, the groups differ in terms of the organization and relational interaction in which they achieve a vocal-tract gesture in a repetitive task. Thus, the results indicate that the fluent speech of stutterers and control subjects differs with respect to an organizational speech behavior that has been shown (in this and other experiments, e.g. Gracco and Abbs3)) to be relatively stable in terms of trial-to-trial variability, and is, therefore, considered to be an invariant characteristic of speech motor control. The issue of whether the stutterers' speech motor system exhibits generalized abnormalities throughout a fluency continuum ranging from perceptually fluent speech production through dysfluent speech production can only be resolved by increasing the pool of group comparison data that best reflect speech motor control.

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