# VARIABILITY IN THE ARTICULATORY KINEMATICS OF LIPS AND JAW IN REPEATED /pa/ AND /ba/ SEQUENCES IN ITALIAN STUTTERERS

*Claudio Zmarich, Emanuela Magno-Caldognetto, Kyriaki Vagges*
*Centro di Studio per le Ricerche di Fonetica, C.N.R. -*
*Via Anghinoni, 10 35121 Padova, Italy*

## ABSTRACT

The kinematics of the closing gesture in bilabial stop consonants produced at two different rates by stutterers and controls was investigated. The results show that stutterers score lower than controls in displacement and velocity of movement and that some dynamic measures differentiate the speech production of stutterers from controls.

## INTRODUCTION

Kinematic investigation is more useful than perceptive or acoustic analyses because it can detect the possible minimal anomalies in the fluent speech behaviour of stutterers, and access to levels of decreasing speech variability [1]. Bilabial stop consonants production in stutterers was investigated to verify the hypothesized different responsiveness of stutterers to voiced/voiceless contrasts and to changes in speaking rate [2].

## PROCEDURE

Four stutterers (mean age: 25.25) and four normal subjects (mean age: 28.50) participated in the experiment. All the subjects had a negative history concerning neurological, speech, language and hearing problems, except for stuttering. Stuttering severity, as assessed by the Stuttering Severity Instrument [3], was mild for one subject and severe for three. One subject was never treated for stuttering, two subjects stopped the treatment 7 years before the date of the experiment and one subject 2 years before. All the subjects were instructed to repeat each of the /pa/ or /ba/ syllables in ten sequences and two rates, normal and maximal, with evenly stressed syllables, in random order. For each sequence, the acquisition time was set to 2 seconds. Thus, each subject produced 40 sequences, except for one stutterer that produced 20 sequences. The normal rate was the preferred rate for each subject, and the maximal rate was the fastest rate the subject was able to perform without altering the perceptual characteristics of the phones. Upper lip (UL), lower lip (LL) and jaw (J) movements were recorded and analysed with ELITE, a fully automatic, real-time system for 3D kinematic data acquisition which uses small, non obtrusive, passive markers of 2 mm in diameter attached onto the speaking subject's face. This system ensures high accuracy and minimum discomfort to the subject [4].

In this study, the movements of the markers placed on the central points of the UL, LL and J were analysed. The LL movement was then digitally subtracted from the J movement. Interlabial vertical distance was recorded as the distance between UL and LL, providing a measure of the combined movement (C). Relevant data were then selected from the general tables reporting all the movement and velocity peaks and the acoustic signal segmentations, and considered for statistical analysis.

As our purpose was to consider only perceptively fluent utterances, we paid particular attention to signs of disfluency or defective articulations. Only 9 gestures in different sequences produced by one stutterer were eliminated due to slurred speech. Gestures were eliminated when one or both of the following conditions occurred: irregular movement form and frequency for those movements having less than one millimetre of amplitude; presence of more than one peak in the velocity curve referring to a gesture. Moreover, the steady state portions of the movements, mainly corresponding to the open mouth position, were not measured. For the stutterer group, the percentage of eliminated cases was 23.28 out of a total of 4725 gestures (1575x3 articulators). For the control group, the percentage was 20.18 out of a total of 5310 gestures (1770x3 articulators ). In order to assess the spatial and temporal characteristics of



UL, LL, and J during the opening gesture and the closing gesture, the following measurements were taken: a) duration of opening or closing gesture, measured as the time interval between onset of the movement and peak opening or closing position; b) time interval from onset of opening or closing movement to peak velocity; c) displacement, calculated as the distance between onset position and peak opening or closing position; d) peak velocity.For each of these measurements, the effects of the voiced/voiceless contrast and of the different speaking rates on the normal/pathological condition of the subjects were analysed. As to the latter variable, speaking rate was classified in two ways. The first was subject-dependent, i.e.both the normal and the fast rates were related to the subject's own speaking style. The second was a post-hoc rearrangement of the original rates. In fact, to provide an objective rate-dependent group comparison, reference to the duration of C was considered necessary. Four classes were created: 0.050-0.100 (very fast), 0.101-0.150 (fast), 0.151-0.200 (moderate), 0.201-0.250 (slow).Outliers were eliminated.

## RESULTS

The mean number of gestures analysed for each stutterer was 123.2 for the preferred rate condition and 270.5 for the fast rate condition. For the controls there were 164.5 and 278.5, respectively. The mean duration of the C gesture provided a measure of the articulatory rate. At the preferred rate, the stutterers produced 5.29 gestures per sec. and the controls 5.55 gestures. At the fast rate, the stutterers produced 8.71 and the controls 9.00 gestures per sec. Only the data relative to the closing gestures are presented here, as this gesture appeared to differentiate the stutterers from the controls better than the opening gesture [5]. The data obtained with the subject-dependent rate will be presented first. Statistical analysis was applied involving a planned series of separate comparisons between stutterers and controls within each rate using the Mann-Whitney survey ($p = .005$). A non-parametric survey was chosen because of the non-normal distribution of the data (different variance, different number of cases and presence of ratio data).Tab.1 shows the median values and the significant comparisons between stutterers and controls for gestures displacement, velocity and duration. In addition to these direct measures, indirect measures are also presented: peak velocity / displacement ratio (a measure of the mass-normalized stiffness, cf. [6]); time from movement onset to peak velocity / total movement time x 100 (a measure of the simmetry of the velocity profile, cf. [7]), and parameter c (a metric of the velocity profile shape, cf. [6]). The formula of paramenter c is :(peak vel. / displacement) x movement duration. For these indirect measures the normative studies [6,7] established the following trade-off between rate and scores: both vel./displacement ratio and % of time to peak velocity vary positively with rate, while parameter c varies inversely. For the % of time to peak vel., our data show an interesting counterevidence to the norms, probably because we did not count the steady state portion of the gestures and the multiple-peak velocity gestures, which are much more frequent at slower rates.

The stutterers perform the gesture with less amplitude and velocity compared to the controls, while duration is less affected. The differences between groups for /p/ are more significant than /b/. The data of velocity/displacement ratio are greater for the controls than for the stutterers, because the velocity is proportionally higher in the controls. Considering the % of time to peak velocity, the general trend for stutterers is to have higher values than controls. Generally speaking, all these effects are more evident for J and less for UL (see Tab.1).In interpreting these data, however, we must take into account the intersubject variability, in part due to the task itself, as the subjects articulated according to personal feelings of comfortable and maximal rates. A way of minimizing these effects was to relate all the kinematic values of each subject to four classes, based on the duration of C.Unfortunately, as individual data were not equal in number across the four categories, statistical comparisons were precluded

*Table 1.Comparisons of the kinematic measures of the movement across speaking rates. Measures included displacement (D: mm), duration (T:sec), peak velocity (V: mm/sec), peak vel./displ. ratio (R), parameter c. (P) and % of time from onset to peak velocity (%). Values were compared within each rate using the Mann-Whitney statistic (p=.005).*

| *Stutterers vs Controls* | | | /p/ closing | | | | | | /b/ closing | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Art. | Rate | | D | T | V | R | P | % | D | T | V | R | P | % |
| UL | Preferred | S | 1.14 | 0.180 | 13.5 | 11.50 | 1.90 | 57.1 | 1.19 | 0.170 | 14.9 | 11.22 | 1.78 | 56.6 |
| | Preferred | C | 1.62 | 0.140 | 21.7 | 13.16 | 1.84 | 53.8 | 1.28 | 0.145 | 17.5 | 12.52 | 1.77 | 57.1 |
| | *p=.005 | | | * | * | * | | | | * | | * | | |
| UL | Fast | S | 2.17 | 0.120 | 29.2 | 13.9 | 1.67 | 53.8 | 1.45 | 0.110 | 20.7 | 16.2 | 1.70 | 53.8 |
| | Fast | C | 1.21 | 0.120 | 18.2 | 14.5 | 1.74 | 50.0 | 0.87 | 0.110 | 15.5 | 16.5 | 1.69 | 50.0 |
| | *p=.005 | | | | | | | * | * | | * | | | |
| LL | Preferred | S | 1.14 | 0.170 | 20.7 | 17.26 | 3.00 | 56.2 | 1.30 | 0.170 | 20.2 | 14.40 | 2.52 | 57.8 |
| | Preferred | C | 2.35 | 0.170 | 40.6 | 17.00 | 2.35 | 50.0 | 2.41 | 0.190 | 43.2 | 17.33 | 3.21 | 56.2 |
| | *p=.005 | | * | | * | | | * | * | | * | * | * | |
| LL | Fast | S | 0.59 | 0.100 | 15.0 | 22.2 | 2.20 | 50.0 | 0.81 | 0.100 | 22.35 | 21.57 | 2.26 | 50.0 |
| | Fast | C | 1.86 | 0.110 | 37.8 | 19.7 | 2.04 | 45.4 | 1.98 | 0.100 | 41.68 | 20.10 | 2.16 | 50.0 |
| | *p=.005 | | * | * | * | | | * | * | | * | | | |
| J | Preferred | S | 6.60 | 0.170 | 73.4 | 10.77 | 1.91 | 55.2 | 7.27 | 0.180 | 69.8 | 14.40 | 1.88 | 57.5 |
| | Preferred | C | 7.84 | 0.180 | 111.8 | 11.59 | 2.19 | 52.9 | 8.24 | 0.190 | 109.9 | 17.33 | 2.22 | 56.2 |
| | *p=.005 | | * | | * | * | * | * | * | | * | * | * | |
| J | Fast | S | 5.02 | 0.100 | 86.1 | 16.17 | 1.62 | 45.8 | 5.25 | 0.100 | 88.7 | 15.62 | 1.62 | 50.00 |
| | Fast | C | 6.38 | 0.110 | 99.9 | 15.45 | 1.69 | 50.0 | 6.45 | 0.100 | 120.2 | 17.24 | 1.72 | 50.00 |
| | *p=.005 | | * | * | * | | * | * | * | | * | | * | |

As an example, when the data for the J closing gestures are plotted on a three-dimensional space, with velocity and displacement related to different rates and the graphics of the subjects are paired according to comparability of number of occurrences for the different rates, a picture of extreme inter-subject variability appears. Apart from this variability, the values for the J movements in the production of /ba/ (b) are lightly higher than /pa/ (p) for most of the subjects. While the general trend is to reduce the amount of displacement and velocity along with the increase in speaking rate, the stutterers S2 and S3 are the only subjects that present some increase of displacement and velocity. To conclude, the dramatic contrast between S1 and C1 shows us that different speakers are able to perform the same phonetic gestures at comparable rates with an extremely divergent use of the articulators, and they do this without becoming disfluent.

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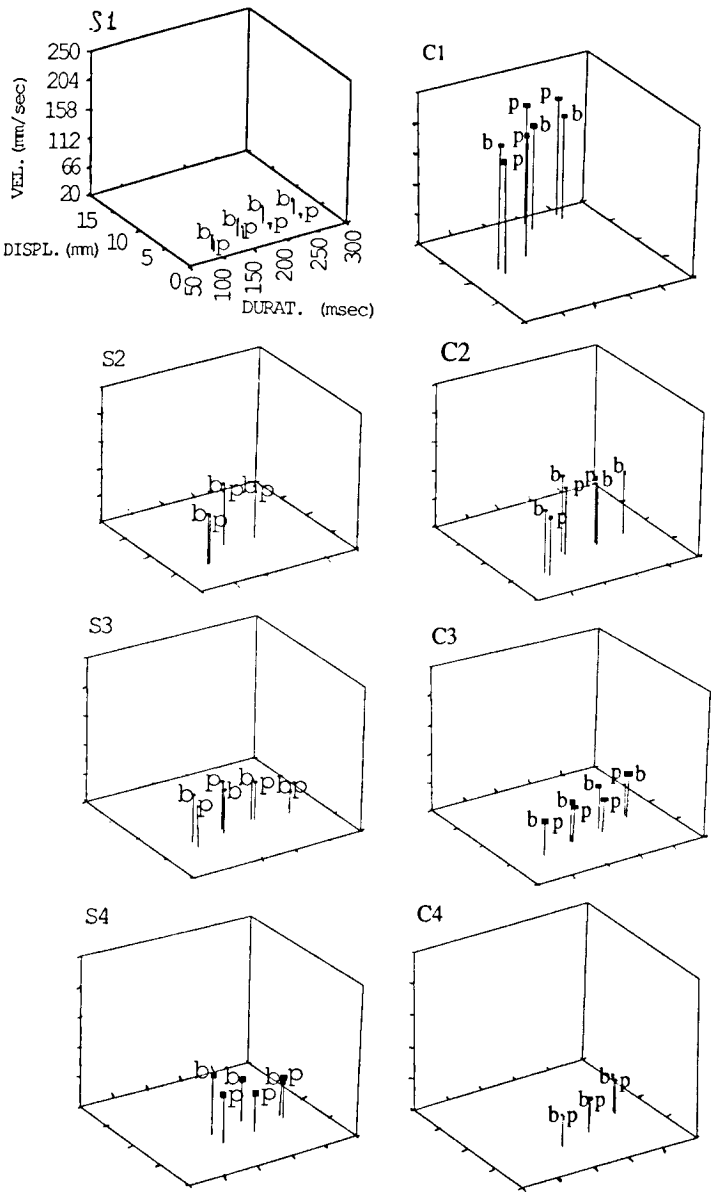


FIG.1. *Individual peak vel. and displacement means of the closing gestures for J as a function of four different rates for /p/ and /b/: 100:50-100; 150:101-150; 200:151-200; 250:201-250.Stutterers (S1, S2, S3, S4) and Controls (C1, C2, C3, C4) are paired according to comparability of number of occurrences along with the rates (S1-C1 produced most gestures for 100, and so on).*