Formant Structures of Vowels Produced by Stutterers in Normal and Fast Speech Rates

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Abstract

The aim of this study is to analyse the steady—state portion of the first two formants (F1) and (F2) in the production of [CV] sequences, containing vowels [i, a, u], pronounced in two speech rates (normal and fast), by groups of untreated and treated stutterers, and control subjects. Locus equations have been calculated to observe for potential differences in coarticulatory strategies between the three groups. Data analyses reveal a reduction of vowel space for stutterers at a normal speaking rate. When speech rate increases, no reduction of vowel space is noticeable for the latter group of speakers, contrary to treated stutterers and controls. No significant differences between the three groups have been observed in coarticulatory strategies.

1. Introduction

The aim of this research is, firstly, to analyse the formant structure of vowels produced by stutterers and treated stutterers, and to compare their data with those of control subjects. Secondly, we will examine the effects of speech rate increase on the formant structures of vowels, and also on the behaviour of the three groups of speakers. Finally, locus equations will be calculated to observe for potential differences in coarticulatory strategies between the three groups. Concerning control subjects, several studies [1] have shown that an increase in speech rate could provoke a compression of durations and a reduction of the vowel space, *i.e.* a certain centralisation of vowels in this space. What would the result be for stutterers or treated stutterers, knowing that the majority of studies [2] have shown vowel space reduction in a normal speech rate condition for stutterers? In this perspective, a Blomgren *et al.* [3] work confirmed reduction of the vowel space in fluent speech of stutterers. However the Prosek *et al.* [4] work had not shown such conclusions, as no vocalic centralisation had appeared in fluent or disfluent speech of stutterers. The present investigation is of double interest: a) it attempts to provide additional data concerning a possible reduction of the vowel space of stutterers in normal speech rate; b) it tries to verify whether an "undershoot" phenomenon in fast speech rate would appear or not. Our *hypotheses* are: a) a more restricted vocalic space should be noticed in stutterers' fluent speech; b) consequently, no further vowel centralisation should be observed when stutterers speak faster; c) the more reduced vocalic space expected in stutterers' production could be explained by the fact that they use different coarticulatory strategies, in terms of gestural economy (see, *e.g.*, [5, 6]), compared with control speakers and treated stutterers.

2. Experimental procedure

2.1. Speakers and corpus

Fifteen adult speakers from 25 to 30 years, comprising five control subjects without speech disorders, five stutterers and five treated stutterers, had to pronounce sentences containing [CVp] sequences ten times, where C was either [p], [t] or [k] and V [i], [a] or [u]. Each subject had to repeat the following nine sentences in normal and fast speech rates:

1. C'est une pipe à Bordeaux.
2. C'est une pape à Bordeaux
3. C'est une poupe à Bordeaux.
4. C'est une type à Bordeaux.
5. C'est une tape à Bordeaux
6. C'est une toupe à Bordeaux.
7. C'est une kippa bordeaux.
8. C'est une coupe à Bordeaux.
9. C'est une cape à Bordeaux.

It should be mentioned that no subject had any particular regional accent. By the term 'treated stutterers', we refer to stutterers who had followed a treatment program against stuttering in the last five years, anterior to this work.

Only fluent repetitions were analysed, *i.e.* sentences which had been pronounced without any abnormal pause (due to stuttering).

Repetitions were recorded with the help of a Sennheiser e845S© microphone, which was connected to a computer (Sound Card RealTek AC97©) by using the Audacity© freeware (Sampling frequency: 44100 Hz – 16 bits).

Findings graphically represented in this article relate to data from three groups: the control group (CG), the non-treated stutterers' group (NTS) and the treated stutterers' group (TS).

2.2 Acoustic measures and vocalic space

2.2.1. Acoustic measures

Measurements carried out were: duration of the vowels, from onset of a clear formant structure to its offset, triggered by the subsequent [p], in the [CVp] span; the vowel formant structure (F1 and F2) in order to obtain vowel space area; F2 vowel onset and F2 vowel mid-point values were also extracted in order to calculate locus equations. Other measures were also taken but will not be reported here as they are not relevant to this investigation.

2.2.2. Calculation of vowel space

The area of the triangle in the F1xF2 space was calculated using Heron's formula:

$$\sqrt{p(p-a)(p-b)(p-c)}$$

with : $p = \frac{1}{2}(a+b+c)$

and a,b and c corresponding respectively to the length of the three sides of the triangle.

$$a = \sqrt{((xc - xb)^2 + (yc - yb)^2)}$$

$$b = \sqrt{((xa - xc)^2 + (ya - yc)^2)}$$

$$c = \sqrt{((xa - xb)^2 + (ya - yb)^2)}$$

This value (in kHz²) provides information about the space used to obtain distinctions between vowels.

3. Results

3.1. Formant structures

Before analysing formant structures, it is important to mention that vowel durations were shorter in fast speech rate compared with normal speech rate, for all groups.

Figures 1 and 2 show average values of the first two formants of vowels [i, a, u] in [pV] context, pronounced by the three groups in normal and fast speech rates, respectively.

3.1.1. Vowel [i]

For vowel [i], the mean value of F1 was 256 Hz, and F2 was 2108 Hz for the control group (CG). The same sound was evaluated with a first resonance at 286 Hz and a second one at 1847 Hz for stutterers (NTS). Therefore, the main difference between the two productions comes from F2, *i.e.* presumably tongue advancement in the oral cavity. Thus, the tongue may be in a less anterior position for the NTS group.

Productions of treated stutterers (TS) looked like those of control speakers (CG), since the first formant is at 255 Hz and the second one at 2110 Hz for TS. Non-pathological subjects and treated stutterers present similar results relating more or less to aperture of the oral cavity (F1) and the forward – backward movement of tongue-body (F2).

In summary, values of vowel [i] are comparable for treated stutterers and controls but not for stutterers, because the latter apparently show lesser tongue-body advancement.

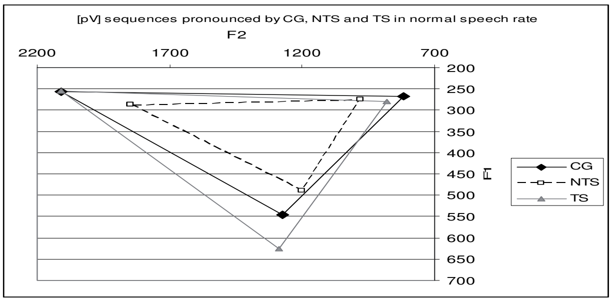

Figure 1: *Vocalic triangle CG, NS and NTS for [pVp] sequences pronounced in normal speech rate.*

Increase in speech rate only provokes a minor increase of the F1 value from 256 Hz to 272 Hz, when the control group speaks faster. F2 decreases to attain 1954 Hz in fast speaking rate. The same phenomenon was observed for TS: F1 increases very slightly in fast speech rate (257 Hz) and F2 decreases to 1976 Hz. This fact is not confirmed for stutterers: a stability of F1 (286 Hz *vs*. 282 Hz) and F2 values (1847 Hz *vs*. 1855 Hz) is noticed in normal and fast speech rates.

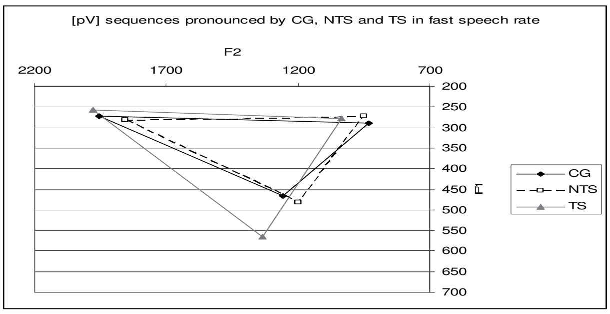

Figure 2: *Vocalic triangle NS, CG and NTS for [pVp] sequences pronounced in fast speech rate.*

Consequently, no significant difference appears between the productions of vowel [i] in normal and fast speaking rates for stutterers.

3.1.2. Vowel [a]

For non-pathological speakers, CG, pronouncing [a], F1 is at 545 Hz and F2 at 1276 Hz. These values differ from those of non treated stutterers, NTS, since the F1 mean value was 489 Hz and 1203 Hz for F2 in normal speech rate. F1 and F2 values were respectively 626 Hz and 1288 Hz for the group of treated stutterers, TS.

Therefore, tongue elevation seems to be higher for NTS, and lower for TS.

When speech rate increases, it is mainly the value of the first formant which is modified, since it decreases from 545 Hz to 467 Hz in the control group. The second resonance remains stable (1276 Hz in normal speech rate *vs*. 1258 Hz). Some modifications were observed for the same vowel in treated stutterers' speech. Thus, the value of F1 diminishes (626 Hz *vs*. 565 Hz) when the speaker is given instructions to speak as fast as possible. F2 values are stable across normal and fast speech rates (respectively 1288 Hz and 1334 Hz). No significant differences were noted when stutterers' speech rate increased, F1 remaining relatively stable between 489 Hz in normal speech and 482 Hz in fast speech. So also is F2, whose values are stable in normal and fast speech at 1203 Hz and 1200 Hz, respectively.

3.1.3. Vowel [u]

The first formant average value of vowel [u], produced by the control group, was 268 Hz. No difference was revealed for stutterers, with measures at 274 Hz, contrary to treated subjects, with F1 at 280 Hz.

F2 was measured at 817 Hz for CG, at 882 Hz for TS and at 978 Hz for NTS.

Accelerating speech rate provokes a slight modification of [u] for the control group: F2 increases from 817 Hz to 931 Hz. However, this difference is not significant (because of a relatively high standard deviation) and must be carefully considered. F1 is located at 290 Hz when speech rate increases. Similar remarks can be made for TS, since F2 was 1037 Hz in the same condition. Finally, it is interesting to note that F1 and F2 values are comparable for stutterers in the two speech rates: F1 attains 274 Hz in normal speech rate and 272 Hz in fast speech rate; F2 corresponds to 978 Hz, when subjects speak without tempo instructions, and to 948 Hz when they are asked to speak quickly.

3.2. Comparison of vowel space areas

It is important to notice that calculation of vowel space area has no functional significance in itself; it serves as an index of the general pattern of change in the vowel space. Analysis of the area of the vocalic triangle in sequences [pV] reveals higher values for control speakers and treated stutterers, compared with results obtained for stutterers. For CG, the area is 0.18 kHz², for TS, it is 0.22 kHz² and for NTS, it is 0.09 kHz². As regards CG and NTS, this area decreases in fast speech rate: measures for CG and TS correspond respectively to 0.09 kHz² and to 0.14 kHz² when speaking rate increases. Comparison of the vocalic triangle area for stutterers does not show any difference between the two speech rates: 0.09 kHz² in normal speaking rate, and 0.09 kHz² in fast speech rate.

Consequently, the area of the vowel space is systematically smaller for stutterers than for the other speakers in normal speech rate. In fast speech, vowel space areas are comparable for all groups.

Similar patterns have been obtained for [tVp] and [kVp] sequences.

Table 1. *Comparison of vocalic triangle areas.*

	Area (kHz²)	CG	NTS	TS
[pVp]	Normal speech rate	0.18	0.09	0.22
	Fast speech rate	0.09	0.09	0.14
[tVp]	Normal speech rate	0.17	0.09	0.17
	Fast speech rate	0.1	0.08	0.11
[kVp]	Normal speech rate	0.17	0.12	0.18
	Fast speech rate	0.11	0.13	0.11

3.3. Locus equations

We thought that differences observed in formant structures between stutterers and the control group could be explained by the use of different coarticulatory strategies. Such a hypothesis gave us the idea to calculate locus equations. However, we did not observe significant differences between the three groups, as can be seen, for an example, on Figure 3.

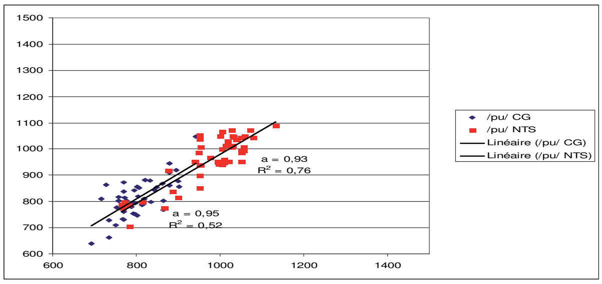

Figure 3: *Locus equations for [pu] sequences pronounced by control speakers and stutterers.*

To sum up, locus equations do not explain formant structure differences observed between stutterers and controls.

4. Conclusions

In conclusion, although vowel durations were compressed in fast speech for all subjects, this reduction was, however, not directly correlated with centralisation in stutterers, as the vowel space of the latter was already significantly reduced (*hypothesis a and b*). Contrary to *hypothesis c,* locus equations did not reflect expected differences in coarticulatory behaviour. Results for stutterers could be interpreted in terms of lack of articulatory flexibility (Van Lieshout *et al.*, 2004). This means that stutterers would not adapt their gestures to demands related to articulatory speeding up, in fast speech conditions. However, such an assumption needs to be verified experimentally.

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