Visible Articulatory Characteristics of the Italian Stressed and Unstressed Vowels

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Abstract
This research focuses on the study of the multidimensionality of the visible articulatory movements in the production of the Italian stressed and unstressed vowels. Lip and jaw movements were recorded and analysed with a fully automatic real-time system for 3D kinematics data acquisition. The data obtained showed that jaw opening and lower lip protrusion were the most relevant articulatory parameters in distinguishing among the vowels.

Introduction
Integration of articulatory data with acoustic and perceptual data is fundamental in developing a phonetic theory of vowels and can find important applications in linguistic description, articulatory features system, psycholinguistic research, and technological applications. The Italian vowel system is considered to be very simple, and the parameters used to describe it in terms of the features high/low and front/back. The feature rounded/unrounded, high/low, and front/back are the most important features for distinguishing among Italian vowels.

Method
Lip and jaw movements were recorded and analysed with ELITE [5], a fully automatic, real-time system for 3D kinematics data acquisition. It uses small, non-obtrusive, passive markers of 2mm diameter, realised by reflective paper, attached onto the speaking subject's face. In this study, the markers were placed on the central points of the vermilion border of the upper lip and of the lower lip, at the corners of the lips, and at the centre of the chin. The markers placed on the tip of the nose and on the lobes of the ears served as reference points to eliminate the effects of the head movement. The following articulatory parameters corresponding to phonologically significant features were analysed:
- lip height (LH), calculated as the distance between the markers placed on the central points of the upper and lower lips; this parameter may be correlated with the feature high/low.
- lip width (LW), corresponding to the distance between the markers placed at the corners of the lips, a parameter which correlates with the feature rounded/unrounded.
- jaw opening (JO), corresponding to the distance between the markers placed at the centre of the chin and the tip of the nose. This distance is primarily due to the jaw opening but it is also influenced by the movement of the skin of the chin. This parameter is correlated with the feature high/low.
- anterior-posterior movement of the upper lip (UP) and lower lip (LP), calculated as the distance between the markers placed on the central points of either the upper or lower lip and the line passing from the markers placed on the lobes of the ears. This parameter correlates with the feature protruded/retracted.

Results
Table 1. Normalised mean values (mm) pooled over subjects and repetitions for each articulatory parameter and each vowel.

<table>
<thead>
<tr>
<th></th>
<th>/i/</th>
<th>/e/</th>
<th>/u/</th>
<th>/l/</th>
<th>/o/</th>
<th>/u/</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH</td>
<td>8.6</td>
<td>9.6</td>
<td>13.6</td>
<td>15.0</td>
<td>15.1</td>
<td>8.7</td>
</tr>
<tr>
<td>stressed</td>
<td>7.6</td>
<td>8.7</td>
<td>10.6</td>
<td>11.2</td>
<td>8.1</td>
<td>7.1</td>
</tr>
<tr>
<td>JO</td>
<td>6.6</td>
<td>7.8</td>
<td>12.6</td>
<td>14.1</td>
<td>11.2</td>
<td>3.3</td>
</tr>
<tr>
<td>stressed</td>
<td>5.3</td>
<td>6.7</td>
<td>9.0</td>
<td>5.9</td>
<td>5.1</td>
<td>6.1</td>
</tr>
<tr>
<td>LW</td>
<td>0.1</td>
<td>0.5</td>
<td>1.1</td>
<td>0.9</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td>stressed</td>
<td>1.2</td>
<td>0.8</td>
<td>1.2</td>
<td>1.2</td>
<td>3.2</td>
<td>3.9</td>
</tr>
<tr>
<td>UP</td>
<td>-1.1</td>
<td>-0.3</td>
<td>-2.0</td>
<td>-2.1</td>
<td>2.6</td>
<td>3.9</td>
</tr>
<tr>
<td>stressed</td>
<td>-1.2</td>
<td>-1.0</td>
<td>-1.5</td>
<td>-1.5</td>
<td>3.2</td>
<td>3.9</td>
</tr>
<tr>
<td>LP</td>
<td>-1.4</td>
<td>-1.2</td>
<td>-3.3</td>
<td>-2.9</td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td>stressed</td>
<td>-0.6</td>
<td>-1.1</td>
<td>-1.9</td>
<td>-1.9</td>
<td>2.2</td>
<td>3.4</td>
</tr>
</tbody>
</table>

For both stressed and unstressed vowels, there was no significant correlation between lip height and lip width, as well as between lip width and lower lip protrusion. Stressed vowels showed also a correlation between lip height and jaw opening. For both stressed and unstressed vowels, the values may be either positive or negative depending on the parameter taken into consideration.
values, while LH and JO are always positive.

The results of the ANOVA showed that jaw opening is the articulatory parameter that better distinguishes both stressed and unstressed vowels since it defines 4 degrees of jaw opening. In fact, Fig. 1 shows that stressed vowels are clustered in 4 groups, /u, o, u, /, /e, /, /, /, and /a/. As for the unstressed vowels, in Fig. 1, JO distinguishes /a, /, /, /, and /a, /.

LH, which is traditionally considered to be parallel to jaw opening, does not identify all the degrees of opening defined by JO (see Fig. 1). Moreover, the extension of its movement always shows greater values than JO, cf. Table 1. It is clear that lips not only move in synergy with the jaw, but also in an independent specific manner.

LW divides both stressed and unstressed vowels in two groups: rounded vowels and unrounded vowels, see Fig. 1.

As for the two protrusions, LP is the parameter that best distinguishes both stressed and unstressed vowels. As shown in Fig. 1, stressed and unstressed vowels are divided into 4 groups, i.e. two degrees of protrusion and two degrees of retraction. In particular, for stressed vowels, a higher degree of protrusion characterises /a/ and /a/ with respect to /a/, while /a/ and /a/ are more retracted than /a/ and /a/, see Table 1.

Using the parameters resulting most significant for distinguishing the vowels (jaw opening, lower lip protrusion and lip width), a three-dimensional representation of the stressed and unstressed vowel space was plotted in Figs 2a and 2b respectively. As can be observed there is a tendency to reduce the values of the parameters from the stressed to the unstressed condition, even though the trend is not systematic.

DISCUSSION

Our data confirm the cooccurrence of rounding and protrusion for the Italian language. In fact, all the vowels with positive values of lip width, i.e. /e, e, a, e/, also have negative values for both upper, and lower lip protrusion. That is, unrounded vowels are always also non protruded. Similarly, vowels with negative lip width values, i.e. the rounded vowels /u, o, u, /, are characterised by positive values of upper and lower lip protrusion, that is, they are also protruded.

Jaw opening and lower lip protrusion are the parameters that better distinguish the vowels. It should be noted though, that differences in jaw opening with respect to lip height may be due to the marker placed on the chin: the position of this marker was influenced not only by the jaw opening but also by the movement of the skin especially during the lip protrusion.

Based on the values of the parameters analysed, the reduction of the unstressed with respect to the stressed vowels was confirmed. Moreover, the unstressed mid vowels are more similar to the stressed mid-high /e/ and /e/ rather than to the mid-low stressed /e/ and /e/.

REFERENCES

