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Stressed and unstressed vowel production in hearing-impaired speech

Luisa Barzaghi and Beatriz Mendes

Faculdade de Fonoaudiologia - LIAAC
Catholic University of São Paulo
luisa@pucsp.br; bmendes@pucsp.br

Abstract

The aim of this experimental study is to investigate the production of stressed and unstressed syllables in Brazilian Portuguese (PB) by two hearing-impaired subjects, one with moderate (HI-M) and the other with severe hearing loss (HI-S). A normal hearing-subject's (NH) speech production is taken as reference for the sake of spectrographic analysis. The acoustic parameters investigated were the duration of the speech segments and F1 and F2 frequencies of the vowel /a/ in different stress positions in a controlled phonetic context. Results show differences in the acoustic parameters due to degree of hearing loss of these subjects, suggesting, as expected, less control of prosodic and segmental production.
Keywords: hearing impairment, vowels, formant frequencies, duration.

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1. Introduction

Results of studies based on the acoustic analysis of the speech production of the hearing-impaired have pointed out the following aspects: difficulties in implementing the voicing contrast (1; 2); lack of transitional cues, indicating a lower degree of coarticulation (3); differences regarding F2 trajectories; longer duration of segments (4; 5) stereotyped displacements of the tongue body and excessive opening of the jaw (6). On the other hand, studies on auditory perception of the stop consonants and other speech segments by hearing-impaired subjects show that perception is altered by many factors and that the degree of hearing loss by itself does not account for the variability in identifying and discriminating sounds, although, in general, it gets worse as the hearing loss increases (7; 8) affecting speech production, both in segmental and prosodic levels. In Portuguese, stressed syllables are longer than unstressed; duration is the main correlate of lexical and phrasal stress in Brazilian Portuguese, since segments in those positions are characterized by longer duration values (9). The purpose of this study is to investigate the production of stressed and unstressed syllables of Brazilian Portuguese (PB) by two hearing-impaired subjects, one with moderate and the other with severe hearing loss taking the production of a hearing subject as reference.

2. Method

The *corpus* and subjects of this study were the same used in the previous studies (10, 4). All the subjects were native speakers of PB, from Sao Paulo, Brazil. Three subjects participated in the production task: a normal-hearing (NH, subject 1) 35-year-old woman with clear speech; a 17 year-old, female, with congenital moderate bilateral sensorineural hearing loss, (HI-M, subject 2); and a 16 year-old, female, with bilateral sensorineural hearing loss, severe in the right ear and profound in the left, acquired at 18 months old after meningitis (HI-S, subject 3). Both hearing impaired subjects have been engaged in an oral approach rehabilitation program at Derdic-PUC/SP, and wear hearing aids since diagnosis. By the time of the recordings, they were attending regular school. Figure 1 shows hearing thresholds of the better ear for hearing impaired subjects.

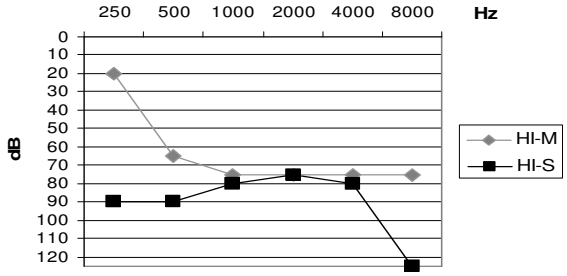

Figure 1: *Hearing thresholds of better ear for moderate hearing (HI-M) and severe hearing (HI-S) impaired subjects.*

The *corpus* consisted of two-syllable words initiated by one of the six stops of PB (/p/, /b/, /t/, /d/, /k/, /g/) inserted in a carrier sentence *Diga* ____*baixinho* . The words are paroxytons, which happens to be the most frequent stress pattern in PB (11) and presents a CVCV pattern (V=/a/; /t/ as second consonant). The recordings were done in studio conditions, ten repetitions for the six sentences, randomly organized in lists and digitalizated at 22 kHz sampling rates using CLS, Kay Elemetrics. The acoustic analysis (Multispeech, Kay Elemetrics and Praat - 4.3.19 - Paul Boersma e David Weenick) included: F1 and F2 frequency at the steady portion of the vowels in stressed and unstressed positions in the two-syllable target words and in the unstressed vowel of the preceding word ("diga"). Both absolute and relative duration measures for vowel /a/ were extracted. In order to compare the values corresponding to the acoustic parameters measured, non parametric tests for more than three unrelated samples (Kruskall-Wallis) or for two unrelated samples (Mann-Whitney) were applied, comparing stressed and unstressed vowel as produced by each subject.

3. Results

The results of absolute and relative duration measurements are displayed in table 1 and 2 respectively. Comparisons between vowel duration values in the three studied positions (unstressed vowel in the word preceding the target word-UVP, stressed-SV and unstressed vowels-UV in target words) in six consonant contexts, for each subject were made. Results of the analysis of the production of the unstressed vowels in the word preceding the target (UVP) words for NH and HI-S subjects showed they were shorter in all contexts, considering both absolute and relative measurements ($p<0,001$). But this

tendency is altered for the HI-M subject, except for the context of the consonant /b/, where the duration of the unstressed vowel was shorter than the stressed vowel, considering only the absolute measurement ($p<0,43$). Otherwise, on the contexts of /p/ and /d/, no significant differences between unstressed vowels in the word preceding the target (UVP) and stressed vowel in the target word (SV) were found, both considering absolute and relative values. The preceding vowel on the contexts /t/ and /k/ was longer than the stressed vowel, considering absolute and relative values ($p<0,001$) and it was longer considering only the relative value in the context of consonant /g/ ($p<0,02$). The comparison between stressed (SV) and unstressed vowels (UV) in the target word, showed that they were longer for all the three subjects in all contexts, considering absolute and relative measurements.

Table 1: Absolute duration (ms) measurements of the unstressed vowel in the word preceding the target words (UVP) and the stressed (SV) and unstressed vowels (UV) in the target words in six consonant contexts as produced by the three subjects (NH, HI-M,HI-S)

Subj	**UVP**	**A pa**	**A ba**	**A ta**	**Ada**	**A ca**	**A ga**
NH	avg (sd)	89 (5)	85 (7)	90 (5)	92 (5)	95 (3)	98 (6)
HI-M	avg (sd)	81 (5)	87 (7)	85 (6)	99 (5)	93 (8)	92 (10)
HI-S	avg (sd)	67 (10)	63 (4)	84 (10)	81 (11)	79 (13)	80 (12)
Subj	**SV**	**pA**	**bA**	**tA**	**dA**	**cA**	**gA**
NH	avg (sd)	135 (11)	142 (11)	133 (9)	150 (10)	131 (8)	156 (7)
HI-M	avg (sd)	78 (5)	93 (6)	73 (4)	95 (6)	76 (4)	78 (10)
HI-S	avg (sd)	191 (14)	190 (11)	188 (14)	199 (17)	194 (17)	182 (14)
Subj	**UV**	**patA**	**batA**	**tatA**	**datA**	**catA**	**gatA**
NH	avg (sd)	44 (3)	43 (4)	50 (5)	47 (5)	46 (4)	49 (4)
HI-M	avg (sd)	32 (5)	38 (17)	41 (11)	39 (6)	42 (6)	37 (7)
HI-S	avg (sd)	33 (8)	27 (7)	46 (12)	50 (17)	44 (9)	43 (6)

Table 2: Relative duration measurements of the unstressed vowel in the word preceding the target words (UVP) and the stressed (SV) and unstressed vowels (UV) in the target words in six consonant contexts as produced by the three subjects (NH, HI-M,HI-S)

Subj	**UVP**	**A pa**	**A ba**	**A ta**	**Ada**	**A ca**	**A ga**
NH	avg (sd)	7 (0,5)	7 (0,9)	7 (0,5)	8 (0,5)	8 (0,4)	8 (0,5)
HI-M	avg (sd)	7(0,5)	8 (0,7)	790,6)	8 (0,4)	8 (0,6)	8 (0,7)
HI-S	avg (sd)	5 (0,9)	5 (0,2)	6 (0,9)	6 (0,6)	6 (1,3)	6 (1)
Subj	**SV**	**pA**	**bA**	**tA**	**dA**	**cA**	**gA**
NH	avg (sd)	11 (1)	12 (1)	11 (1)	12 (1)	11 (1)	13 (1)_
HI-M	avg (sd)	7 (0,5)	8 (0,4)	6 (0.4)	8(0,5)	6 (0,2)	8(0,5)
HI-S	avg (sd)	15 (1)	15 (1)	14 (1)	15 (1)	15 (1)	14 (1)
Subj	**UV**	**patA**	**batA**	**tatA**	**datA**	**catA**	**gatA**
NH	avg (sd)	4 (0,3)	4 (0,5)	4 (0,5)	4 (0,4)	4 (0,3)	4 (0,3)
HI-M	avg (sd)	3 (0,5)	3 (1)	4 (0,9)	3(0,4)	4 (0,5)	3 (0,6)
HI-S	avg (sd)	3 (0,6)	2 (0,5)	4 (0,9)	4 (1)	3 (0,6)	3 (0,4)

The relative duration values of all the sentence segments considered in this study are displayed in figures 2, 3 and 4. Although the stressed vowel has longer duration compared to the unstressed vowel in the target word context, the reduction degrees in unstressed syllable positions were found to differ.

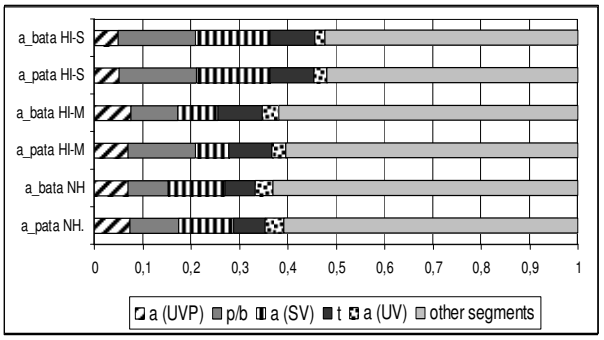

Figure 2: *Relative duration measurements of the unstressed vowel in the word preceding the target words (UVP) and stressed (SV) and unstressed vowels (UV) in the target words in bilabial contexts, produced by the three subjects.*

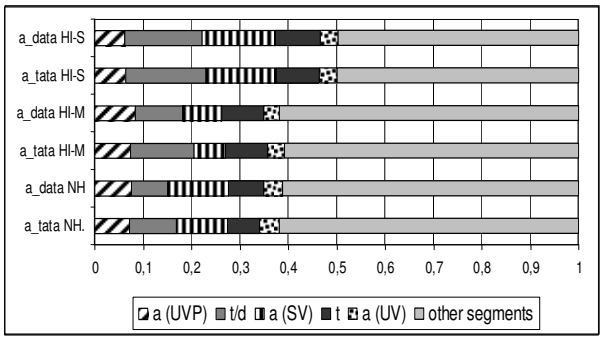

Figure 3: *Relative duration measurements of the unstressed vowel in the word preceding the target words and stressed and unstressed vowels in the target words in alveolar contexts, produced by the three subjects.*

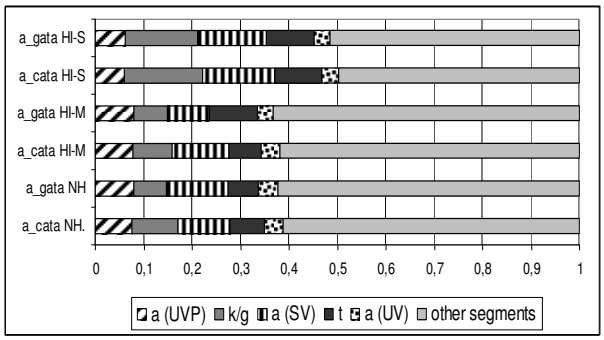

Figure 4: *Relative duration measurements of the unstressed vowel in the word preceding the target words and stressed and unstressed vowels in the target words in velar contexts, produced by the three subjects.*

The results of F1 and F2 frequency measurements of the unstressed vowel in the word preceding the target word (UVP) and stressed (SV) and unstressed vowels (UV) in the target word are presented in table 3.

The comparison between F1 frequency values of vowels in stressed (SV) and unstressed (UV) positions in the target words showed significant differences for all the contexts for the three subjects of the study ($p<0.001$).
In the same way, the comparison between F1 frequency values of vowels in the unstressed syllable of the word preceding the target words (UVP) and the stressed vowel (SV) in the target words showed that there is significant difference for all the contexts for the three subjects of the study ($p<0.001$).
The F1 frequency values of vowels in the syllable stressed position were higher than those of unstressed positions for all subjects in all stop consonant contexts. For illustration purposes, in Figure 5, the distribution of F1 and F2 vowel frequency values only in the bilabial stop consonant context for the three subjects is displayed.

Table 3: *F1 and F2 frequencies of the unstressed vowel in the word preceding the target words (UVP) and stressed (SV) and unstressed (UV) vowel in the target words produced by the three subjects (NH, HI-M,HI-S) in six consonant contexts (/p/,/b/,/t/,/d/,/k/,/g/)*

		UVP	UVP	SV	SV	UV	UV
Subj	**PATA**	**A_p F1**	**Ap F2**	**pA F1**	**pA F2**	**patAF1**	**patA F2**
NH	avg (sd)	576(19)	1560 (58)	802 (62)	1382 (51)	545(21)	1348(60)
HI-M	avg (sd)	719 (27)	1742 (79)	908 (24)	1439 (49)	702(41)	1513(46)
HI-S	avg (sd)	650 (80)	1550(78)	1061(38)	1627(84)	497(21)	1551(90)
Subj	**BATA**	**A b F1**	**Ab F2**	**bA F1**	**bA F2**	**batAF1**	**batAF2**
NH	avg (sd)	591 (44)	1531(74)	794(60)	1395(42)	537(19)	1395(76)
HI-M	avg (sd)	699 (51)	1850 (150)	876 (30)	1449 (84)	637(57)	1617(140)
HI-S	avg (sd)	675 (37)	1473(59)	1060(37)	1619(67)	488(21)	1573(68)
Subj	**TATA**	**At F1**	**At F2**	**tA F1**	**tA F2**	**tatAF1**	**tatAF2**
NH	avg (sd)	581 (23)	1580(97)	735(15)	1367(64)	540(14)	1322(22)
HI-M	avg (sd)	716(31)	1957(103)	899 (35)	1558 (80)	763(57)	1559 (85)
HI-S	avg (sd)	681 (49)	1708(54)	1052(33)	1608(32)	503(40)	1522(89)
Subj	**DATA**	**Ad F1**	**Ad F2**	**dA F1**	**dA F2**	**datAF1**	**datAF2**
NH	avg (sd)	562 (24)	1534(52)	747(67)	1381(64)	545(17)	1359(61)
HI-M	avg (sd)	720 (34)	1917 (104)	870 (42)	1576 (108)	701(47)	1593(81)
HI-S	avg (sd)	684 (19)	1697(34)	1024(47)	1638(36)	506(47)	1593(60)
Subj	**CATA**	**Ac F1**	**Ac F2**	**cA F1**	**cA F2**	**catAF1**	**catAF2**
NH	avg (sd)	577 (19)	1669 (65)	744 (23)	1488 (20)	541(18)	1339(71)
HI-M	avg (sd)	674 (57)	2029 (141)	870 (39)	1638 (142)	708(30)	1566(83)
HI-S	avg (sd)	693 (39)	1651(70)	1049(30)	1661(52)	539(66)	1602(69)
Subj	**GATA**	**Ag F1**	**Ag F2**	**gA F1**	**gA F2**	**gatAF1**	**gatAF2**
NH	avg (sd)	576 (23)	1664 (50)	738 (22)	1494 (58)	539 (19)	1348(75)
HI-M	avg (sd)	712 (35)	1978 (152)	854 (48)	1676(137)	697(49)	1575(91)
HI-S	avg (sd)	658 (63)	1687(63)	1069 (45)	1682(83)	555(64)	1582(86)

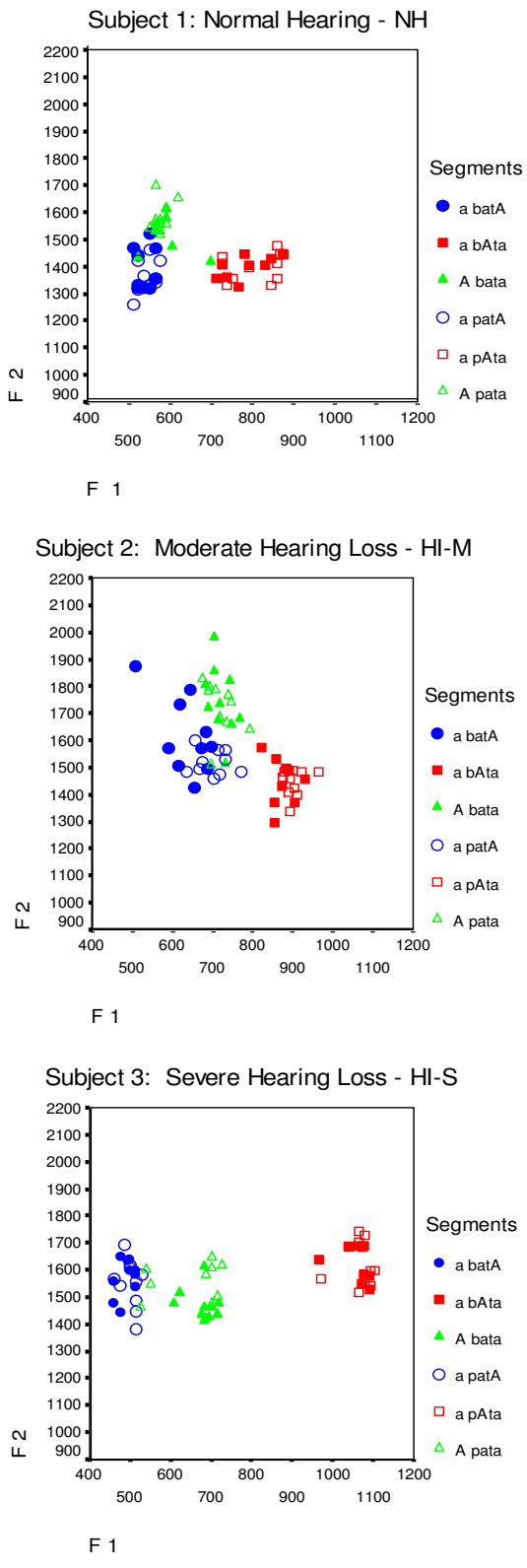

Figure 5: Distribution of F1 and F2 values of the unstressed vowels preceding the target words (UVP) and the stressed (SV) and unstressed vowels (UV) of the words "pata" and "bata" in the carrier phrase

4. Discussion

Spectrographic analysis of the vowels produced by the hearing impaired subject with severe hearing loss as compared to the other subjects' productions showed her production strategies are quite different from the other two. She produced extremely lengthened vowels in stressed position. The stressed-to-unstressed duration ratio was larger for the hearing impaired subject (HI-S) than for the normal hearing (NH) and moderate hearing impaired subjects (HI-M). The lengthening of the vowel by the severe hearing impaired was counterbalanced by reducing unstressed vowels. This compensation strategy was found to affect other segments of the carrier sentence as well. F1 values for stressed (SV) and unstressed vowels (UV) are wider apart, suggesting a great magnitude of jaw opening in stressed syllable positions and mid tongue position in unstressed vowels. Formant frequencies of the unstressed vowel indicate the production of a mid central vowel instead of the low to mid allophone as expected for Brazilian Portuguese. Furthermore, F2 values were found to be undifferentiated indicating lower degree of coarticulartion. The results of the acoustic measures of the vowels produced by the subject with moderate hearing loss as compared to the normally hearing subject show that there is a greater dispersion of formant frequency values and duration of stressed vowels were found to be rather unstable.

5. Conclusions

In Brazilian Portuguese unstressed syllables following the stressed are expected to be reduced. For all the three subjects vowel duration increase in syllable stressed position. The three subjects in this study reduced vowels in unstressed position of the target word, but the degree of reduction was quite different. The hearing impaired subject with severe hearing loss produced the highest degree of reduction.

As expected F1 frequency values of the stressed vowels were higher for all subjects. However, it is important to emphasize that the increase of F1 frequency values observed in the speech of the subject with severe hearing loss indicates an excessive jaw opening in stressed position. Also, the relation between F1 and F2 of vowels in unstressed position is quite different, producing changes in vowel quality. The results show that differences in the acoustic parameters occurred due to degree of hearing loss of these subjects suggesting less control of prosodic and segmental production as hearing loss increases. These data point out specific characteristics concerning prosody and segment interaction in the hearing impaired subject's production under analysis.

6. References

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