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An acoustic comparison of formant frequencies in individuals with normal hearing, profound and severe hearing impairment

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Abstract

The purpose of the present research was to found out the differences in vowel formant production in 156 speakers, exactly between 46 individuals with normal hearing, 36 with severe (M=78.43, SD=16.07) and 74 with profound hearing impairment (M = 108.10, SD = 7.69). The F2 values in anterior vowel production are lower and F2 formant values are higher in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals. The range of F1 from high to low vowels is smaller in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals. The formant space in The F2-F1 diagram is the smallest in individuals with profound hearing impairment, and the greatest in normal hearing individuals. The formants that are influenced by the degrees of jaw opening (F1) and that are low frequency first formants ([i], [e], [O], [o], [u]) between severe hearing impairment group and normal hearing group don't statistically significantly differ at sig. 0.05. Profound hearing impairment group statistically significantly differ from the severe hearing impairment group and from the normal hearing group. The same pattern is present in the low frequency second formants of vowels [E], [A], [O], [o], [u]. In the high frequency second formant production ([i], [e]) all the groups are statistically significantly different. Statistically significant similarity between normal hearing group and profound hearing group is observed and a statistically significantly difference between the two groups of hearing impairment in the first formant production of the vowel [E]. We can conclude that according to the cited researches the formant range, especially of F2, is reduced and the vocal formant space restricted most in the profound hearing impaired individuals.

1 Introduction

Vowels are minimally kinaesthetcally and maximum auditory controlled, therefore the role of the auditory feedback in vowel production is very important. The lack of the auditory feedback in individuals with profound and severe hearing impairment changes the vowel production space. Several authors claim, that speech production of individuals with severe prelingual hearing impairment is different from the speech of individuals with profound hearing impairment and from those of normal hearing subjects.

Markides (1983) lists segmental errors, both vocalic and consonantal, and deviances in suprasegmental features including problems in controlling phonation, fundamental frequency, and timing; with the reference to vowel production, substitution, neutralization, prolongation, diphthongisation, and nasalisation.

Murphy & Dodds (2007, 248-250) mention the characteristics on voice and suprasegmental level by poor voice quality, slow rate, poor breath control, poor rhythm, incorrect and/or unstable pitch, poor volume control, excessive laryngeal tension, and on segmental level by lack of differentiation in the production of vowels, neutralization, substitution of diphthongs for vowels, true diphthongs are incorrect, extra breath before vowels, incorrect duration and nasalization of vowels, by predictable and developmental consonant errors, like assimilation, reduplication, cluster reduction, stopping, fronting, deaspiration, affrication, deaffrication, prevocalic voicing, postvocalic devoicing, /h/ deletion initially, weak syllable deletion, gliding of liquids, vocalisation of liquids in the speech of those with the severe and the profound hearing impairment.

Speakers with the hearing impairment show less differentiated vowels and a more centralised vowel space. F1 and F2 formant frequencies show reduced ranges during the production of the different vowel qualities, there can be an extensive overlap of vowel areas and a tendency toward the neutral [≅] (Angelocci, Kopp & Holbrook, 1964, Ryalls, Larouche & Giroux, 1983, Fletcher, 1995).

Such reduced differentiation of vowels has been attributed to limited auditory feedback and the relative invisibility of articulatory gestures needed for vowel production (Monsen, 1976). Higher frequencies tend to be more affected as hearing sensitivity is greatly reduced above 1000 Hz for individuals with hearing impairment. As a result, generally, more errors have been reported for the high and the middle vowels compared to the low ones and for the front than the back vowels. The high frequency, low intensity F2 formants of the high vowels are more likely to be affected than the lower-frequency, more intense F2 formants of the back vowels. In addition to the generally reduced perception of F2 formants, tongue placement along the front-back axis in the oral cavity is difficult to perceive visually. On the other hand, better residual hearing in the region of F1 frequencies and relatively better visibility of tongue height associated with jaw displacement, which can be accessible in speech reading, makes variation in F1 more prominent (Nicolaidis & Sfakiannaki, 2007).

In Subtelny's, Whitehead's and Samar's report of 4 deaf women speech production, some aberrant features in the vocal tract configuration were identified for vowels produced with excessive pharyngeal resonance: these features included neutralization of the tongue position, elevation of the hyoid, and a retraction of the tongue, associated with a deflection of the epiglottis in the lower pharynx. Comparisons of the formants for vowels [ι], [u] and [a] produced by the women with hearing impairment with mean formant values for these vowels produced by the normal-hearing women revealed no consistent pattern of second-formant deviation. The formant structure evaluated on isovowel lines disclosed consistent neutralization of vowels, with F2 values clustering in the 1500–2100 Hz frequency range, which is attributed to the observed restricted horizontal movements of the tongue within the oral and pharyngeal cavities. If such restrictions affect the production of all vowels, a lower F2 might be assumed for the front vowels, which normally have a high F2. A higher F2 frequency would be anticipated for back vowels, which normally have a low F2 (Subtelny, Whitehead, Samar, 1992, 574-579).

Shizuo and Ryuzaemon (1957) report that the distribution of the formant frequencies of each kind of vowel on the F1 - F2 plane of the five Japanese vowels uttered in isolation by 35 children with profound and severe hearing impairment (aged 6 to 11), which were measured utilizing an sound spectrograph, and compared with those of 8 normal hearing children (aged 7 to 12), shows that those of the afflicted children deviate significantly from the normal range especially for [ι] and [o]. The tendency toward perceptual confusion regarding the type of vowel corresponds well to the deviation of the formant frequencies. The relations between the formant frequencies of the five Japanese vowels of each of the deaf children were classified into six types: F2 range reduced, F2 range reduced and rotated, F2 range reduced and [o] and [a] close together, F2 range reduced and [i] and [e] close together, F2 range neutralized, and F2 range reduced with F1 raised.

In order to know the abnormalities in the speech sounds of the children with profound and severe hearing impairment, Kenkichi, Hirotaka and Hideo (1975) the following results concerning the spectral of vowels obtained: (1) The differences in the spectra of vowels were found between the normal hearing and hearing impaired group. (2) The spectra structure of vowels was observed to be much influenced by the degree of hearing loss in the hearing impaired group. The frequency regions of the formants of vowels were shifting to lower frequency region, and moreover the characteristic differences in the spectra among five vowels were decreasing. (3) In the hearing impaired group with severe hearing loss, the individual differences in the spectra of vowels were remarkable, but the irregularities in the spectra were not always proportional to the degree of hearing loss. (4) as regards to the children with hearing impairment, whose hearing had been impaired after three years of age, it was noticed that the spectra of their vowels resembled to those of the normal hearing children.

2 Aim and methods

2.1 Aim

The purpose of the research was to find out the differences in vowel formant production between individuals with normal hearing and those individuals with profound and severe hearing impairment. The hypotheses were:

- H1: The vowel production measured with F1 and F2 formant values of normal hearing subjects differ from individuals with severe hearing impairment.
- H2: The vowel production measured with F1 and F2 formant values of normal hearing subjects differ from individuals with profound hearing impairment.
- H3: The vowel production measured with F1 and F2 formant values of individuals with severe hearing impairment differ from individuals with profound hearing impairment.
- H4: the F2 values in anterior vowel production are lower and F2 formant values are higher in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals.
- H5: The range of F1 from high to low vowels is smaller in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals.
- H6: The formant space in The F2-F1 diagram is the smallest in individuals with profound hearing impairment, and the greatest in normal hearing individuals.

2.2 Methods:

Subjects: Experimental group: 110 children and adolescents[1] with profound (74) and severe (36) hearing impairment (43 % males, 57 % females, age range 5 – 23 years, mean 13 years, 10 with severe and 100 with profound hearing impairment) were included in the study. All presented severe and profound severe sensorineural prelingual deafness (severe hearing impairment M=78.43, SD=16.07, profound hearing impairment: M = 108.10, SD = 7.69). All the subjects were fitted with conventional hearing aids and didn't have any form of development disease or disorder.

Control group: 46 normal hearing subjects (63 % males, 37 % females, age range 5 – 45, mean 13 years) were included in the study as control group. All of the hearing subjects had no other development disease or disorder.

[1] The research was made in accordance with the Declaration of Helsinki (1983).

Table 1: Descriptive statistics of the mean values of hearing loss for right and left ear and total mean

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Mean of hearing loss, right ear	normal hearing	46	/	/	/	/	/
	severe hearing impairment	36	78,8712	17,77500	2,96250	34,09	120,45
	profound hearing impairment	74	108,7174	7,68669	,89356	92,09	127,73
Mean of hearing loss, left ear	normal hearing	46	/	/	/	/	/
	severe hearing impairment	36	77,9899	20,14788	3,35798	34,09	140,00
	profound hearing impairment	74	107,4877	10,04686	1,16792	74,82	128,64
Total mean of hearing loss	normal hearing	46	/	/	/	/	/
	severe hearing impairment	36	78,4306	16,06578	2,67763	34,09	109,09
	profound hearing impairment	74	108,1026	7,69254	,89424	92,41	127,27

Variables: gender, age, degree of hearing loss, F1 and F2 formant frequency values for seven vowels[2] ([ɩ], [ɛ], [E], [A], [O], [o], [ʊ][3]) of slovenian language (Crombach's alpha: 0.9718). **Data acquisition:** The slovenian test of articulation of Globačnik (1999) and an additional list of pictures, written by Košir, Smole, Ozbič, were used. The test battery of articulation used by all speech and language therapists in Slovenija, is a set of well known frequent words with simple and complex phoneme structures.

Analysis tools: The speech of all subjects was recorded on a DAT recorder Sony model n.o. TCD-D8, with a microphone Sennheiser, model MD 441 U with minimum deviation from 0 to 20000 Hz. The data were stored with CoolEdit2000 and analyzed with tools as SFS, Praat, and SpeechAnalyzer. The statistical analysis was made with SPSS 13.0 for Windows.

Statistical analysis: frequency analysis, Kolmogorov - Smirnov test, Anova – post hoc Bonferroni analysis. The data were normalized.

3 Results

In table 2 and figures 1 and 2 the values of the first and second formants between individuals with normal hearing and individuals with both severe and profound hearing impairment are displayed.

Normal hearing speakers show larger range in F2 formant production from anterior to posterior vowel (2875 Hz - 1554 Hz) in comparison with speech production in individuals with severe (2458 Hz - 1538 Hz) and profound hearing impairment (2281 Hz - 1646 Hz) and greater differences in F1 between high and low vowels (523 Hz - 861 Hz) in comparison with speech production in individuals with severe (507 Hz – 846 Hz) and profound hearing impairment (635 Hz – 816 Hz).

[2] The analyzed vowels were stressed vowels.

[3] The schwa is omitted due to frequently omission or substitution with [ɛ] or [E] in speech of deaf subjects.

From the figures 1 and 2 it is clear, that the formant space in profound hearing impairment is smaller than in the severe impairment and that the space in severe hearing impairment is smaller than the space in the normal hearing individuals. The greatest differences are in anterior vowel production: normal hearing individuals differentiate the three anterior vowels much greater than those with severe and profound hearing impairment.

Table 2: Descriptive statistics of the first and second formant values for the slovene vowels in individuals with normal hearing (NH), severe (SHI) and profound hearing loss (PHI) (mean, standard deviation, minimum and maximum)

		N	Mean	Std. Deviation	Minimum	Maximum
variables						
[ɩ] f1	NH	46	523	85,09	287	698
	SHI	36	507	129,73	241	729
	PHI	74	635	171,11	283	1552
[ɩ] f2	NH	45	2875	303,49	2156	3493
	SHI	36	2458	286,45	1733	3146
	PHI	74	2281	388,89	1368	3630
[ε] f1	NH	45	516	90,75	345	743
	SHI	36	534	115,60	298	816
	PHI	74	647	157,69	258	1337
[ε] f2	NH	45	2567	270,64	1938	3352
	SHI	36	2228	285,27	1642	2811
	PHI	74	2039	407,80	815	3514
[E] f1	NH	45	730	129,44	439	1065
	SHI	34	596	130,91	309	867
	PHI	74	684	174,35	249	1153
[E] f2	NH	45	2246	265,80	1261	2812
	SHI	35	2091	415,66	674	2724
	PHI	74	1955	345,37	664	2805
[A] f1	NH	46	861	133,70	618	1178
	SHI	36	846	145,43	542	1095
	PHI	74	816	179,94	223	1302
[A] f2	NH	46	1554	181,44	1143	1839
	SHI	36	1538	220,96	1087	2001
	PHI	74	1646	257,23	459	2660
[O] f1	NH	44	605	95,89	424	824
	SHI	35	646	149,07	250	1078
	PHI	74	721	149,87	283	1165
[O] f2	NH	44	1170	109,76	898	1425
	SHI	36	1221	234,70	523	1686
	PHI	74	1431	224,57	592	1854
[o] f1	NH	46	549	64,08	414	704
	SHI	36	587	106,42	246	841
	PHI	74	673	136,41	237	1113
[o] f2	NH	46	1120	156,95	799	1579
	SHI	36	1165	193,84	529	1527

	PHI	74	1354	234,10	522	1868
[ʊ] f1	NH	46	529	78,39	367	729
	SHI	36	509	117,17	193	693
	PHI	74	610	143,07	262	1182
[ʊ] f2	NH	46	1026	152,83	707	1345
	SHI	36	1049	176,35	443	1380
	PHI	74	1208	190,44	580	1741

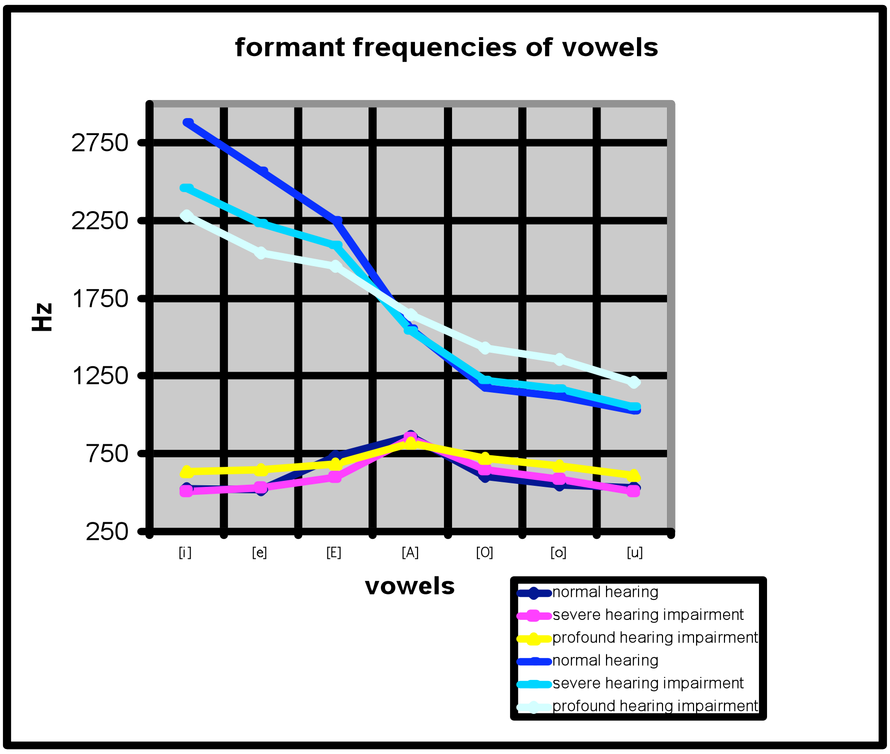

Figure 1: Vowel production: F1 and F2 in normal hearing, severe deaf and profound deaf subjects

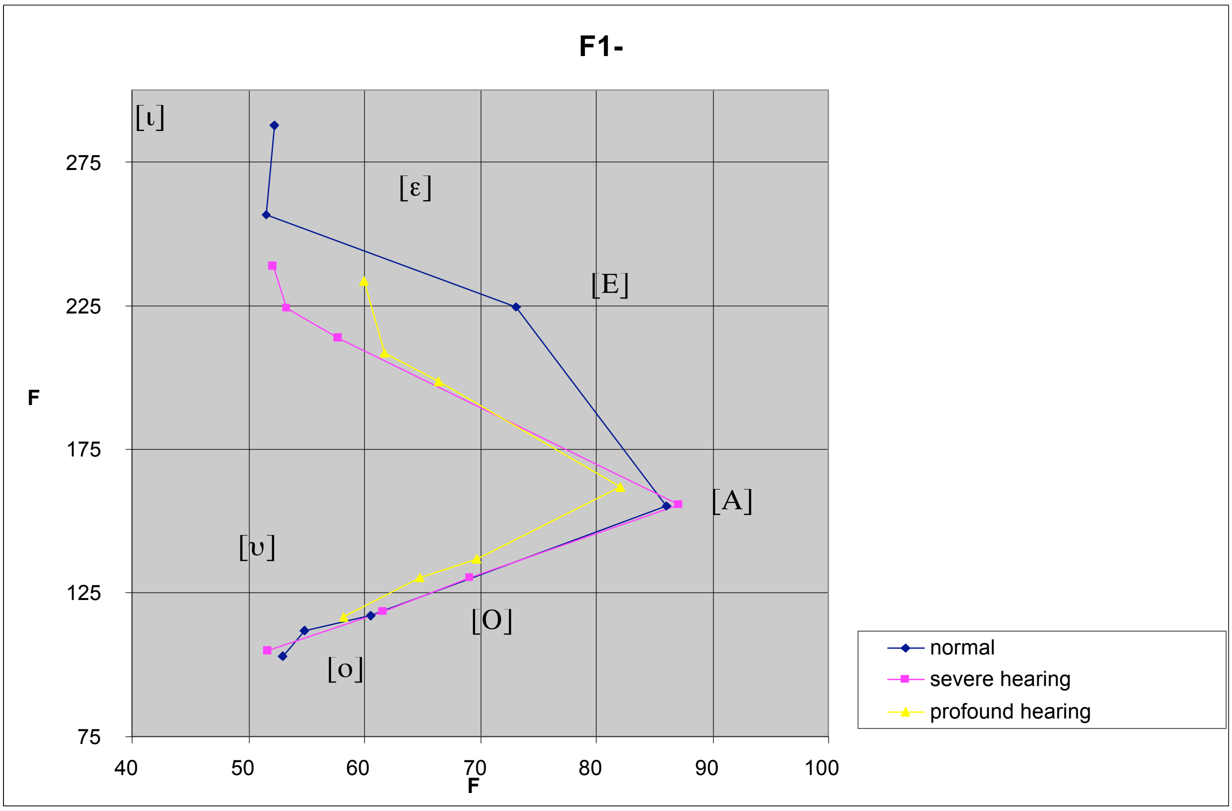

Figure 2: Vowel production in F2 – F1 space of normal hearing, severe deaf and profound deaf subjects

In order to analyse the statistically relevant differences between the formant values in individuals with normal hearing, severe hearing impairment and those with profound hearing impairment, in table 3 the means between three groups with post-hoc Bonferroni Anova analysis were tested.

Table 3: Multiple Comparisons - Bonferroni post hoc analysis of vowel formant variables between individuals with normal hearing (NH), with severe (SHI) and profound hearing impairment (PHI)

Dependent Variable	(I) hearing status	(J) hearing status	Mean Difference (I-J)	Std. Error	Sig.	Dependent Variable	(I) hearing status	(J) hearing status	Mean Difference (I-J)	Std. Error	Sig.
[ι] f1	NH	SHI	,0921324	,2014996	1,000	[A] f2	NH	SHI	,0660885	,2157869	1,000
		PHI	-,7932870(*)	,1700173	,000			PHI	-,4438534(*)	,1820724	,048
	SHI	NH	-,0921324	,2014996	1,000		SHI	NH	-,0660885	,2157869	1,000
		PHI	-,8854194(*)	,1840037	,000			PHI	-,5099419(*)	,1970505	,032
	PHI	NH	,7932870(*)	,1700173	,000		PHI	NH	,4438534(*)	,1820724	,048
		SHI	,8854194(*)	,1840037	,000			SHI	,5099419(*)	,1970505	,032
[ι] f2	NH	SHI	,9817009(*)	,1789358	,000	[O] f1	NH	SHI	-,2817812	,2110742	,552
		PHI	1,3884471(*)	,1512737	,000			PHI	-,8083650(*)	,1774111	,000
	SHI	NH	-,9817009(*)	,1789358	,000		SHI	NH	,2817812	,2110742	,552

		PHI	,4067461(*)	,1626078	,040			PHI	-,5265838(*)	,1911812	,020
	PHI	NH	-1,3884471(*)	,1512737	,000		PHI	NH	,8083650(*)	,1774111	,000
		SHI	-,4067461(*)	,1626078	,040			SHI	,5265838(*)	,1911812	,020
[ε] f1	NH	SHI	-,1233725	,1998894	1,000	[O] f2	NH	SHI	-,2784750	,1887059	,426
		PHI	-,9340674(*)	,1689881	,000			PHI	-1,1788411(*)	,1598516	,000
	SHI	NH	,1233725	,1998894	1,000		SHI	NH	,2784750	,1887059	,426
		PHI	-,8106949(*)	,1816494	,000			PHI	-,9003661(*)	,1706268	,000
	PHI	NH	,9340674(*)	,1689881	,000		PHI	NH	1,1788411(*)	,1598516	,000
		SHI	,8106949(*)	,1816494	,000			SHI	,9003661(*)	,1706268	,000
[ε] f2	NH	SHI	,8730370(*)	,1836680	,000	[o] f1	NH	SHI	-,3589092	,1984319	,217
		PHI	1,3239132(*)	,1552744	,000			PHI	-1,0120227(*)	,1674290	,000
	SHI	NH	-,8730370(*)	,1836680	,000		SHI	NH	,3589092	,1984319	,217
		PHI	,4508762(*)	,1669082	,023			PHI	-,6531135(*)	,1812024	,001
	PHI	NH	-1,3239132(*)	,1552744	,000		PHI	NH	1,0120227(*)	,1674290	,000
		SHI	-,4508762(*)	,1669082	,023			SHI	,6531135(*)	,1812024	,001
[E] f1	NH	SHI	,8566762(*)	,2158465	,000	[o] f2	NH	SHI	-,2330920	,1951663	,703
		PHI	,3166426	,1795678	,240			PHI	-1,0355387(*)	,1646735	,000
	SHI	NH	-,8566762(*)	,2158465	,000		SHI	NH	,2330920	,1951663	,703
		PHI	-,5400335(*)	,1968039	,020			PHI	-,8024467(*)	,1782203	,000
	PHI	NH	-,3166426	,1795678	,240		PHI	NH	1,0355387(*)	,1646735	,000
		SHI	,5400335(*)	,1968039	,020			SHI	,8024467(*)	,1782203	,000
[E] f2	NH	SHI	,4369195	,2064635	,108	[ʊ] f1	NH	SHI	,1633876	,2080794	1,000
		PHI	,9158271(*)	,1731769	,000			PHI	-,6149690(*)	,1755691	,002
	SHI	NH	-,4369195	,2064635	,108		SHI	NH	-,1633876	,2080794	1,000
		PHI	,4789076(*)	,1879325	,035			PHI	-,7783566(*)	,1900122	,000
	PHI	NH	-,9158271(*)	,1731769	,000		PHI	NH	,6149690(*)	,1755691	,002
		SHI	-,4789076(*)	,1879325	,035			SHI	,7783566(*)	,1900122	,000
[A] f1	NH	SHI	,1067915	,2203228	1,000	[ʊ] f2	NH	SHI	-,1531623	,1964994	1,000
		PHI	,2974936	,1858996	,335			PHI	-,9866863(*)	,1657984	,000
	SHI	NH	-,1067915	,2203228	1,000		SHI	NH	,1531623	,1964994	1,000
		PHI	,1907021	,2011926	1,000			PHI	-,8335240(*)	,1794377	,000
	PHI	NH	-,2974936	,1858996	,335		PHI	NH	,9866863(*)	,1657984	,000
		SHI	-,1907021	,2011926	1,000			SHI	,8335240(*)	,1794377	,000

* The mean difference is significant at the .05 level (*)

4. Discussion and interpretation

The results show some differences in vowel production between individuals with normal hearing and individuals with profound and severe hearing impairment. It is evident that in vowel production those with normal hearing and individuals with profound and severe hearing impairment have different vowel space.

The greatest differences are between normal hearing and individuals with profound hearing impairment, especially in the second formant values (table 3). In the three groups,

the only formant value that is equal is the first formant of the vowel [A], the most central vowel, where the auditory control is minimal: the only movement required is a jaw vertical movement with minimal tongue movement. In the vowel production we can observe 4 patterns of differences between the three groups:
a. the formant values are statistically significantly equal in the three groups ([A] F1),
b. the formant values of individuals with normal hearing and of those with severe hearing impairment not differ statistically significantly, and formants of individuals with profound hearing impairment statistically significantly differ from both groups – normal hearing and severe hearing impairment ([ɩ] f1, [ɛ] f1, [E] f2,[A] f2, [O] f1, [O] f2, [o] f1, [o] f2, [ʋ] f1, [ʋ] f2)
c. the formants values are statistically significantly different in the three groups ([ɩ] f2, [ɛ] f2)
d. the formants values of individuals with normal hearing and of those with severe hearing impairment differ statistically significantly, meanwhile they not differ from group with profound hearing impairment, and the formant values of individuals with severe hearing impairment statistically significantly differ from both groups – normal hearing and profound hearing impairment ([E] f1).

Table 4: Patterns of differences in formant values in normal hearing, severe hearing impairment and profound hearing impairment group

patterns	**pairs**	**formant values**	**description**
a	NH = SHI PHI = NH SHI = PHI	[A] F1	all equal
b	NH = SHI PHI ≠ NH PHI ≠ SHI	F1: [ɩ], [ɛ], [O], [o], [ʋ] F2: [E],[A], [O], [o], [ʋ]	normal hearing group similar to severe hearing impairment group
c	PHI ≠ NH PHI ≠ SHI NH ≠ SHI	F2: [ɩ], [ɛ]	all different
d	NH ≠ SHI NH = PHI SHI ≠ PHI	F1: [E]	Normal hearing group similar to profound hearing impairment group

The patterns in the table 4 above differ from each other primarily formant frequency – based or/and in the degree of auditory feedback. The formants that are influenced by the degrees of jaw opening (F1) and that are low frequency first formants ([ɩ], [ɛ], [O], [o], [ʋ]) between severe hearing impairment group and normal hearing group don't statistically significantly differ at sig. 0.05. Profound hearing impairment group statistically significantly differ from the severe hearing impairment group and from the normal hearing group. The same pattern is present in the low frequency second formants of vowels [E], [A], [O], [o], [ʋ].

In the high frequency second formant production ([ɩ], [ɛ]) all the groups are statistically significantly different, due to the auditive feedback demanded in the anterior / high vowel production. In the pattern d statistically significant similarity between normal hearing group and profound hearing group is observed and a statistically significantly difference between the two groups of hearing impairment. The [E]s in Slovenian are very different from region to region (dialects) and it is often realized as more or less open [ɛ]. The normal hearing individuals control the [E]s through the auditory feedback, those with profound hearing impairment produce them with kinaesthetically control of the jaw opening, acquired through visual stimuli, too. The individuals with severe hearing impairment try to produce the vowel correctly, but the auditory feedback seems to be insufficient. They produce the [E] higher and more anterior than those with profound hearing impairment; the [E] is more differentiated from [A] and more closed (neutral [ɛ]) than in profound and normal hearing group. In speech production of those with severe hearing impairment are auditory controlled and tends to [ɛ], meanwhile in the speech production of those with profound hearing impairment is visual-kinaesthetically controlled and tends to [A].

If we compare results (total mean, SD, minimum and maximum values of mean) in vowel production between individuals in normal hearing, with profound and severe hearing impairment, in table 2 and figures 1, 2 we can see that there are great differences between the three groups. Comparing the individuals with profound and severe hearing impairment, there are smaller standard deviations in the severe hearing impairment group and higher in the profound one. The means of F1 are usually higher in the anterior and the posterior vowels in the profound hearing impairment comparing with formant values of those with severe hearing impairment; the means of F2 are usually higher in the severe hearing impairment in the anterior vowels, and in the posterior vowels the means of formants are lower comparing to the profound hearing impairment. The vowel space is greater in the individuals with severe hearing impairment than in individuals with profound hearing impairment.

Comparing with formant values of the individuals with normal hearing, a lower F2 might be assumed in individuals with profound and severe hearing impairment for the front vowels, which normally have a high F2, and a higher F2 frequency would be produced for the back vowels, which normally have a low F2. The F1 values are normally higher for the front and the back vowels, both in the individuals with profound and severe hearing impairment, for the middle [A] The F1 is lower. In the individuals with profound and severe hearing impairment the standard deviation is much greater than in those with normal hearing, especially in the F1 variables; the highest SD is in the profound hearing impairment.

The means of F1, that are usually higher in anterior and posterior vowels in individuals with profound than in severe hearing impairment, and the means of F2, that are usually higher in severe hearing impairment in anterior vowels, and lower in posterior vowels, show a smaller vowel space in individuals with profound hearing impairment than in severe one.

Comparisons of the formants for the vowels produced by the individuals with profound and severe hearing impairment revealed neutralization of vowels, with F2 values clustering in the 1049 – 2458 Hz frequency range for severe impairment and 1208 – 2281 Hz frequency range for profound impairment (in subjects with normal hearing 1026 – 2875 Hz), which is attributed to the restricted horizontal movements of the tongue within the oral and pharyngeal cavities. The mean F1 values show a shifted – restricted vertical space, with frequency mean range of 509 – 846 Hz for the individuals with severe hearing impairment and a restricted space with frequency range of 610 – 816 Hz in the profound hearing impairment, comparing with that of the subjects with normal hearing with frequency range of 522 – 860 Hz. The differences between the F2 values are 1073 Hz for profound hearing impairment, 1401 Hz for severe hearing impairment and 1749 for normal hearing speakers; for the F1 values the differences are 206 Hz for profound hearing impairment, 337 Hz for severe hearing impairment and 338 for normal hearing speakers.

The frequencies of vowel formants of the individuals with hearing impaired are in closed correlation with the degree of hearing loss. As the hearing loss increased, the second formant of the front vowels decreased and those of the back values increase, the first formants increase in the extreme back and front vowels and decrease in the middle low vowel; in addition, standard deviations increase in all variables, due to the great variation in the speech production.

Hearing impairment changes the monitoring of speech production and consequently the formant frequencies and the variability of speech production. Individuals with profound hearing impairment show more restricted formant space than individuals with severe hearing impairment; both have smaller formant space than normal hearing subjects.

We can totally accept the fourth, the fifth and the seventh hypotheses, stating that:

H4: the F2 values in anterior vowel production are lower and F2 formant values are higher in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals.

H5: The range of F1 from high to low vowels is smaller in the hearing impaired groups, according to the degree of hearing impairment, compared with the values of normal hearing individuals.

H6: The formant space in The F2-F1 diagram is the smallest in individuals with profound hearing impairment, and the greatest in normal hearing individuals;

The first, second and third hypotheses (H1: The vowel production measured with F1 and F2 formant values of normal hearing subjects differ from individuals with severe hearing impairment. H2: The vowel production measured with F1 and F2 formant values of normal hearing subjects differ from individuals with profound hearing impairment. H3: The vowel production measured with F1 and F2 formant values of individuals with severe hearing impairment differ from individuals with profound hearing impairment.) can be accepted with some explanation: the formants that are influenced by the degrees of jaw opening (F1) and that are low frequency first formants ([ι], [ε], [O], [o], [υ]) between severe hearing impairment group and normal hearing group don't statistically significantly differ at sig. 0.05. Profound hearing impairment group statistically significantly differ from the severe hearing impairment group and from the normal hearing group. The same pattern is present in the low frequency second formants of vowels [E],[A], [O], [o], [υ]. In the high frequency second formant production ([ι], [ε]) all the groups are statistically significantly different. Statistically significant similarity between normal hearing group and profound hearing group is observed and a statistically significantly difference between the two groups of hearing impairment in the first formant production of the vowel [E].

We can conclude that according to the cited researches the formant range, especially of F2, is reduced and the vocal formant space restricted most in the profound hearing impaired individuals.

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