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A high unrounded vowel in Turkish: is it a central or back vowel?

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Abstract

The aim of this paper is to investigate the phonetic properties of a Turkish vowel in which its backness is indefinite. The five members ([ɑ],[ϵ],[i],[u] and the high unrounded Turkish vowel, in short HUTV) of the Turkish vowel system were investigated in five adult native Turkish speaker males. For the articulatory analysis, midsagittal magnetic resonance images were obtained during sustained phonation of the vowels, and the distances of the main constrictions from the glottis and the areas of the oral and pharyngeal cavities were calculated. For the acoustic analysis, both the Turkish vowels' and HUTV-like IPA vowels' fundamental frequencies (f_0) and the first three formants (F_1, F_2 and F_3), were calculated. The acoustic parameters of HUTV were compared both with other vowels' and with those of the IPA vowels'. For the auditory analysis, 220 synthetic stimuli and 26 IPA vowels were used in an identification test. Articulatory analyses revealed that there were no statistically significant differences between HUTV and [u], and HUTV and [ϵ]. Acoustic analyses revealed that there were no statistically significant differences between HUTV and [ϵ], and HUTV and phoneticians' [ɨ] and [ɯ], and [ɤ] vowels. Auditory investigation revealed that the [ɨ] and [ɯ], and [ɤ] vowels perceived as HUTV. These results suggested that HUTV's position in the vowel space was between the [ϵ] and [u] vowels, but its subarea was fairly wide.

Keywords: Magnetic resonance imaging; Speech acoustics; Turkish; Vowels

1. Introduction

1.1. The Turkish phonology

The vowel inventory of Turkish is very symmetrical. There are four high and four low (non-high), four front and four back and four rounded and four unrounded vowels in Turkish. Each of the front vowels pairs up with the corresponding back ones and each of the rounded vowels pairs up with the corresponding unrounded ones (Kornfilt, 1997). The eight vowel phonemes of Turkish (/ɑ/, /ϵ/, /i/, /ɔ/, /œ/, /u/, /y/ and the high unrounded Turkish vowel, henceforth HUTV) based on averaged $F_1 - f_0$ and $F_3 - F_2$ values can be seen in Fig. 1.

The most striking property of Turkish phonology is the fact that the distribution of vowels

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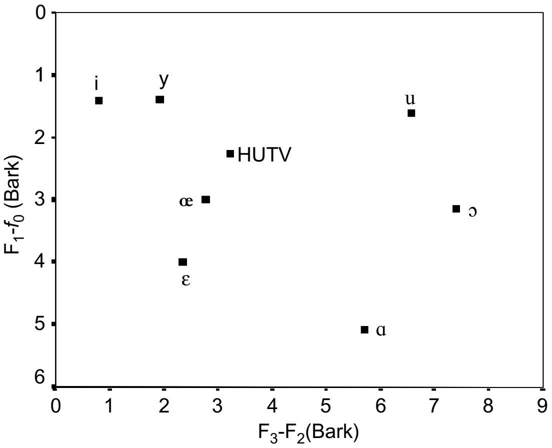

Fig. 1. F_2–F_1 plot marking the averaged positions of Turkish vowels related to men. According to Kiliç's (2003) data.

within a word is governed by vowel harmony. Vowel harmony is expressed in three rules (Lewis, 1967):

(a) If the first vowel of a word is a back vowel, any subsequent vowel is also a back vowel; if the first is a front vowel, any subsequent vowel is also a front vowel.
(b) If the first vowel is unrounded, so too are subsequent vowels.
(c) If the first vowel is rounded, subsequent vowels are either rounded and close or unrounded and open.

According to these rules, it can be generally said that /ɑ/ is followed by /ɑ/, /u/ and HUTV, and HUTV is followed by /ɑ/ or HUTV, in Turkish words. Vowel harmony applies within morphemes as well as across morpheme boundaries:

⟨dalı⟩	'branch + accusative'	[dɑɫɯ]
⟨soru⟩	'question'	[sɔɾu]
⟨ırmak⟩	'river'	[ɯɾmɑk]

Even though the phonologic structure of Turkish strongly suggests that HUTV is phonologically a back vowel, there is disagreement among native Turkish linguists concerning this issue. Some linguists claim that it is a back vowel (Demircan, 1979; Demirezen, 1986), others argue that it is a central vowel (Ergenç, 1989; Selen, 1979).

1.2. The aim of this study

The aim is three-fold: (1) to shed light on the subject of backness of the Turkish vowel called HUTV in this study, and make a decision about its backness, (2) to present scientific data about HUTV which is generally unfamiliar to the speakers of major European languages, because of its nonphonemic status in their languages, (3) to point out the representation problem of high unrounded vowels in the acoustic vowel space.

2. Materials and methods

The articulatory, acoustic and auditory properties of HUTV and other vowels like the [ɑ], [ɛ], [i] and [u] were analyzed, in this study. For articulatory analysis, MRI scanning; for acoustic analysis, fundamental frequency and formant analysis techniques; and for auditory analysis, isolated synthetic vowel-like stimuli and recorded IPA vowels were used.

For statistical analyses, due to small sample size, nonparametric tests were used in SPSS (version 7.5) program, and α level of 0.05 was used as a criterion for statistical significance.

2.1. Subjects

This study was performed on five subjects. They were native Turkish males who spoke the South and South-East Anatolian dialect aged from 22 to 37 with negative histories of speech and hearing pathology, and without metallic implants or prostheses.

2.2. Articulatory analysis

There are two classical methods of making articulatory descriptions of vowels: the highest point of the tongue method and the three parameters method. According to the first one, the highest point of the tongue on the vertical axis determines vowel height, on the horizontal axis does backness. Ladefoged (1993) stated this method was not entirely satisfactory. The second method, i.e., the three parameters model is an approximate description of the dimensions of successive parts of the air chambers within the vocal tract from the glottis to the lips. According to this method, vocal tract shape of vowels can be characterized by: (1) the size of the minimum cross-sectional area; (2) the location of the minimum cross-sectional area from the glottis; (3) the magnitude of lip opening (Fant, 1970; Ladefoged, 1985). Like the first method the three parameters method is also not satisfactory.

Perhaps, the most convenient method for articulatory analysis of vowels is measuring the volumes of oral and pharyngeal cavities that determine F_1 and F_2 values. For this purpose, magnetic resonance imaging (MRI) or computerized tomography techniques are used. Measurements can be done either on a three- or two-dimensional basis. For three-dimensional volumetric analysis of the vocal tract, sophisticated computer assisted methods are necessary, but two-dimensional analysis can be easily done on midsagittal sectional images. In our study, we used MRI technique, and measurements were done on two-dimensional midsagittal images.

MRIs were obtained by using a Toshiba 0.5 Tesla Flexart System. A spin echo pulse sequence (T1 weighted) was used with excitation times (TE) of 17 ms, relaxation times (TR) of 500 ms, and two excitations (1 NAQ). Slice thickness was 8 mm. Each subject laid on the table in supine position and their head and neck were stabilized by using QD head coil and its pads. After the subject's body and head were properly positioned, the scanning was started. The subjects were instructed to produce sustained vowels and remain as motionless as possible during the scanning. Midsagittal MRIs of the subjects were obtained during the sustained production of the [ɑ], [ϵ], [i], [u] and HUTV. A single acquisition time of 14 s for each image was used.

After all images were developed on roentgenograms, they were scanned by a high resolution scanner, and transferred to a computer. Three short straight lines were drawn on these images. The first line represented the glottis level, the second one represented the shortest distance between the palate and the tongue at the place of the main constriction and the third one represented the lip aperture. The slope of the second line was adjusted to intersect the tongue at right angle at the constriction level. The length of this line represented the constriction degree. Afterwards a curved line that represent the vocal tract length was drawn in the following way: firstly, multiple circles that are tangent to each other and the surrounding tissues in the vocal tract, were drawn; later, a broken line that intersects the previous lines at their middle points and the centers of the circles, was drawn; lastly, the broken line was smoothed manually and transformed to a curved line. The partial length of this line remaining between the glottis and the main constriction represented the constriction location (Fig. 2a). The area of the pharyngeal cavity lying between the first and the second lines and the area of the oral cavity lying between the second and the third lines, were also calculated. To exclude the region belonging to the teeth that were invisible in MRIs, two straight lines were drawn from the hard palate to the upper lip and from the tip of the tongue to the lower lip, portions outside of this boundary were not included in the oral cavity (Fig. 2b).

In order to normalize data, constriction locations were divided by vocal tract lengths and multiplied by the mean vocal tract length of the related vowel, and oral and pharyngeal areas were divided by total area of the vocal tract and multiplied by the mean vocal tract area of the related vowel in our subjects. The mean lengths and areas used in normalization were computed across subjects. Both length and area measurements were done using Scicon Image software (Version Beta 4.0.2) by referencing the scales on the images. Measured constriction location lengths and oral, pharyngeal areas for each vowel were compared. For these comparisons, the Mann-Whitney U test was used.

2.3. Acoustic analysis

The formants characterizing different vowels are results of the different shapes of the vocal tract. Therefore, we can also use the formants to predict

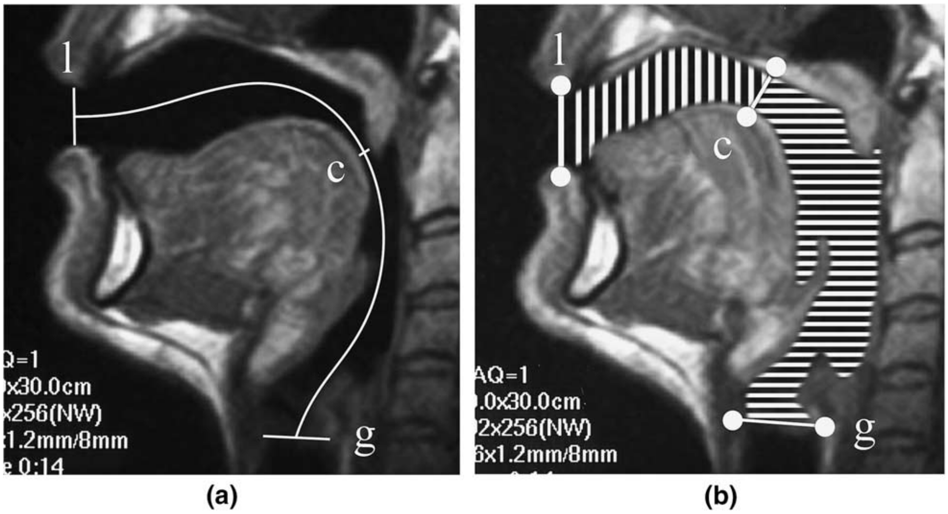

Fig. 2. Two images that show the lines and areas used in articulatory analysis. (a) The left image which belongs to [ɑ] shows three short straight lines and a curved line that represent the vocal tract length, (b) the right one which belongs to [ɛ] shows oral (filled by vertical lines) and pharyngeal (filled by horizontal lines) cavities that were separated with the constriction location. g: the glottis level, c: the constriction location, l: the lip aperture.

the tongue position during articulation of the vowels. Position of a certain vowel in the vowel space may be determined by its fundamental frequency (f_0), first (F_1), second (F_2) and third (F_3) formants. Fundamental frequency is directly and F_1 inversely related to vowel height, F_2 is inversely related and $F_3 - F_2$ (difference between the third and second formants) directly related to vowel backness (Shriberg and Kent, 1995). According to Syrdal (1985), $F_1 - f_0$ represents the height of the vowels; $F_3 - F_2$ represents the backness of the vowels. A chart in which the F_1 or $F_1 - f_0$ values plotted on the ordinate (y axis) and F_2 or $F_3 - F_2$ values on the abscissa (x axis) closely resembles the articulatory vowel space.

For signal capturing and analysis, the Computerized Speech Lab (CSL, Kay Elemetrics, Model 4300B) was used. Because recording of the vowels were impossible in the MRI scanning room due to noise and an intense magnetic field, the acoustic analyses were made in a different place and time. The acoustic signals were captured by a Shure SM 48 microphone placed 15 cm apart from the lips, and saved at 10 kHz sampling rate, and then submitted to the Pitch Extraction subprogram in CSL for measuring f_0 and to the LPC Formant History subprogram for measuring formants. In the latter subprogram, Hamming window and autocorrelation methods were used, and the window size was selected as 10 ms. Two different kinds of recording were done as natural (short) and sustained. For natural vowel recording, subjects were seated in a quiet room and requested to utter the isolated vowels at pitch and loudness levels with which they would feel most comfortable. The durations of the vowels were between 0.2 and 0.5 s. For sustained vowel recording, subjects were laid in supine position and requested to utter the vowels for 14 s just as during MRI scanning. Each vowel both sustained and short ones was uttered three times. The values of f_0, F_1, F_2 and F_3 were calculated. The subjects' mean values were calculated across repetitions. Then the means and standard deviations across subjects were calculated. To understand differences between a vowel for 14 s duration and the natural one, we compared the data for sustained vowels with the data for more natural short vowels. The paired sample t test was utilized, for this comparison. The sustained and short vowels that were uttered by the subjects were listened to another five subjects, to verify the correct pronounciation of the vowels. This experiment revealed all of the short vowels were correctly pronounced, although in the sustained ones HUTV and [œ] vowels were mutually confused three times.

We also measured the f_0 and the first three formants of the [ɨ], [ɯ], and [ɤ] vowels from two archived recordings of phoneticians producing IPA vowels such as IPA Transcription Tutorial (1993) and The Sounds of the International Phonetic Alphabet (Wells and House, 1995). As IPA Transcription Tutorial was a subprogram of CSL, the vowel records were in the computer. The vowels belonging to The Sounds of the International Phonetic Alphabet were captured via CSL's line input.

To normalize data, all f_0, F_1, F_2 and F_3 values (in Hertz) were transformed to Bark values. For this transformation, the formula proposed by Traunmüller (1988) was used. The Bark difference values between F_1 and f_0 and between F_3 and F_2 were calculated from the Bark transformed values, Bark transformed f_0 was subtracted from Bark transformed F_1 and Bark transformed F_2 was subtracted from Bark transformed F_3, and an acoustic vowel space was drawn using these Bark difference values.

The Euclidian distances between HUTV and the phoneticians' [ɨ], [ɯ], and [ɤ] vowels, and the distances among the last three vowels were measured by using $F_1 - f_0$ and $F_3 - F_2$ values. To compare, $F_1 - f_0$ and $F_3 - F_2$ values of HUTV with the other vowels' and HUTV-like IPA vowels', the Mann-Whitney U test was used.

2.4. Auditory analysis

Determination of the vowel category boundaries by psychophysical tests, gives us useful information in addition to articulatory and acoustic analyses of vowels. For this purpose, both natural utterances and synthetic stimuli which can be generated by computer software, are used. Many different stimuli are created which vary in small steps along certain parameters such as F_1 and F_2. Subsequent perception tests investigate how stimuli from a different part of continuum evoke different percepts in listeners. The auditory maps representing results from synthetic stimuli may be different from the acoustic maps containing data taken from many speakers (Rosner and Pickering, 1994).

For this analysis, 220 synthetic stimuli and 26 different IPA vowels (totally 104 vowels) uttered by four phoneticians were used. They were listened to by the subjects. Synthetic vowel-like stimuli were created on a PC with Sound Blaster Live sound card by using Voice Synthesis program (Dr. Speech Software Group, version 3.2). The fundamental frequencies and the F_3 values of these stimuli were constant at 125 and 2500 Hz, respectively. The first formants were between 250 and 950 Hz stepped by 50 Hz. The second formants were between 600 and 2300 Hz stepped by 100 Hz. The 25 stimuli located near the lower right corner of the vowel space were not synthesized because their $F_1 - F_2$ intervals were equal or lesser than 100 Hz, or their F_1 values were greater than F_2 values, and also the 25 stimuli located near the lower left corner of the vowel space that were symmetric of the previous ones were not synthesized because they were unnatural. Durations of all stimuli were 500 ms. Band widths of the formants were 75, 75 and 110 Hz for F_1, F_2 and F_3, respectively. The stimuli were sampled at 11025 Hz. After the synthetic stimuli were synthesized, they were presented to the subjects who were seated in the same quiet room. The synthetic stimuli were presented binaurally over a high quality headphone at a comfortable loudness, and the subjects were requested to categorize and orthographically write down the stimuli that were presented in randomized order. After each stimulus presentation, the subjects had five seconds to respond. Also, the IPA vowels were presented, and the subjects were requested to categorize and write down their perceptions in the same way. This procedure was repeated twice on successive days, if two responses were the same for a certain stimulus or IPA vowel, it was accepted as a valid answer. The mean F_1 and F_2 values were calculated using the stimuli that were perceived as HUTV by all of the subjects. To reveal the relationship between the auditory and acoustic HUTVs, both the Euclidian distance between them was measured by using $F_1 - f_0$ and $F_3 - F_2$ values, and the $F_1 - f_0$ and $F_3 - F_2$ values were compared. For this comparison, Mann-Whitney U test was used.

3. Results

3.1. Measurements on the MRIs

Fig. 3 illustrates the sample MRIs for three vowels. On these images, the whitest areas indicate regions with the highest hydrogen concentrations, such as fatty tissue. The darkest areas show air spaces such as oral and pharyngeal cavity and calcified structures such as bone and teeth. Muscle and connective tissue appear in varying shades of gray.

The subjects' vocal tract lengths, constriction locations and constriction degrees for the five vowels are seen in Table 1. The areas of oral and pharyngeal cavities of the subjects are seen in Table 2. The means and standard deviations of these articulatory measurements can be seen in Table 3. Although the MRI data were normalized, the raw data were used for statistical analysis, because the differences were negligible. When the constriction locations of the vowels were compared with each other, the difference between HUTV and [u] were found statistically insignifi-

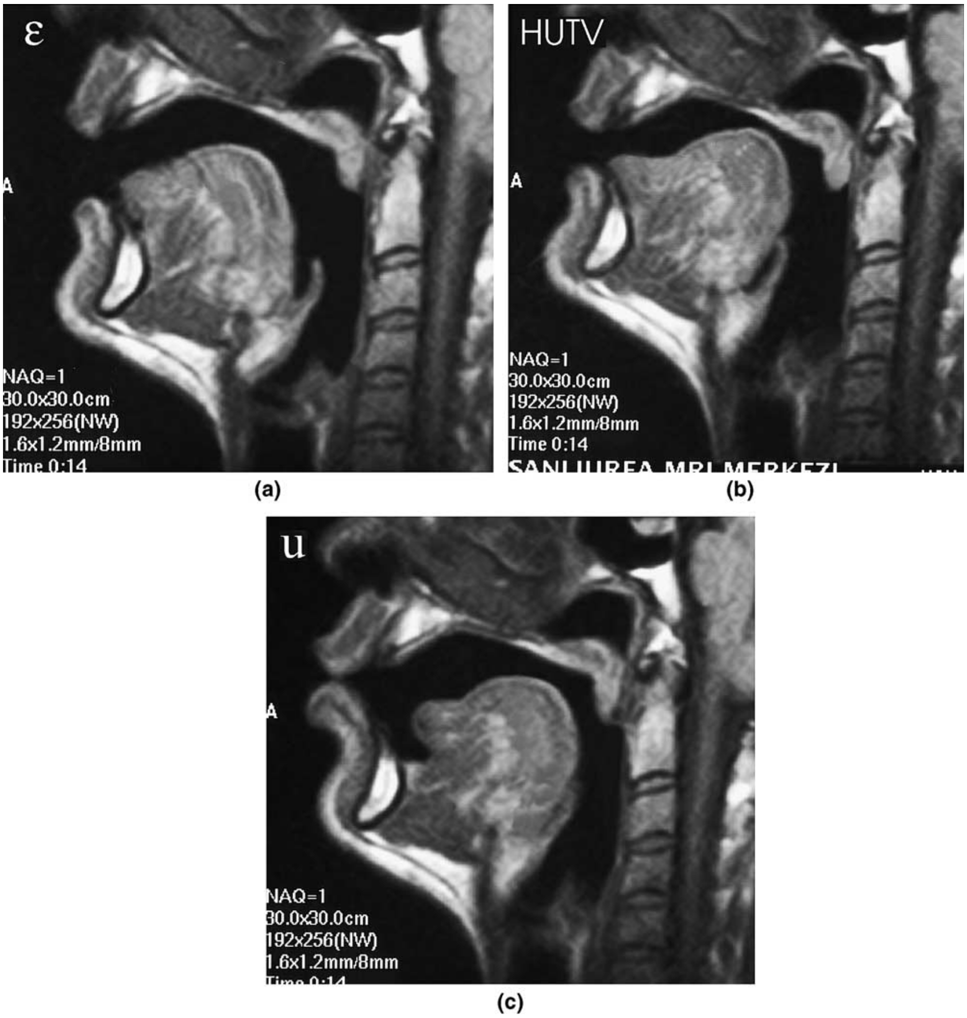

Fig. 3. Sample MRIs obtained during the sustained production of the [ϵ] (a), HUTV (b) and [u] (c) vowel.

Table 1
The subjects' vocal tract lengths (VTL), constriction locations (CL) and constriction degrees (CD) for the five vowels (in mm)

Subjects	Vowels														
	ɑ			ϵ			HUTV			i			u		
	VTL	CL	CD	VTL	CL	CD	VTL	CL	CD	VTL	CL	CD	VTL	CL	CD
AK	168	82	4	164	104	11	163	97	4	158	113	2	167	93	6
MA	175	83	3	172	112	9	175	87	4	160	118	1	165	77	3
MK	158	67	5	156	98	6	158	85	3	153	109	2	164	79	2
IK	160	75	4	171	110	8	175	92	3	165	119	1	171	76	3
FD	191	76	3	181	117	7	182	97	3	179	121	1	192	104	2

Table 2
The areas of oral and pharyngeal cavities according to vowels for five subjects (in mm^2)

Subjects	Vowels									
	ɑ		ϵ		HUTV		i		u	
	Oral	Pharyngeal	Oral	Pharyngeal	Oral	Pharyngeal	Oral	Pharyngeal	Oral	Pharyngeal
AK	1734	1037	880	1751	741	1798	390	2179	1069	1587
MA	1264	1074	548	1871	790	1654	199	2122	1221	1540
MK	1122	911	637	1547	674	1338	214	1775	920	1252
IK	1217	995	594	1652	721	1475	296	1723	976	1331
FD	1458	1114	721	1775	688	1744	186	2163	1115	1512

Table 3
The means and standard deviations of vocal tract lengths (VTL), constriction locations (CL), constriction degrees (CD) (in mm), and the areas of oral and pharyngeal cavities (in mm^2) for the five vowels

Vowels	VTL		CL		CD		Oral		Pharyngeal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ɑ	170.4	13.4	76.6	6.4	3.8	0.8	1359.0	242.8	1026.2	78.0
ϵ	168.8	9.4	108.2	7.4	8.2	1.9	676.0	130.6	1719.2	123.8
HUTV	170.6	9.8	91.6	5.6	3.4	0.6	722.8	45.9	1601.8	191.8
i	163.0	9.9	116.0	4.9	1.4	0.6	257.0	85.8	1992.4	223.9
u	171.8	11.6	85.8	12.3	3.2	1.6	1060.8	117.5	1444.4	144.9

cant. However, other differences were found statistically significant ($p < 0.05$). Comparisons of the oral cavities revealed there was no statistically significant difference between HUTV and [ϵ]. When the pharyngeal cavities of the vowels were compared with each other, the differences between HUTV and [u], and HUTV and [ϵ] were found to be statistically insignificant. However, other differences between HUTV and other vowels were found to be statistically significant ($p < 0.05$).

Because the constriction degrees for back vowels were interfered by the uvula, they were not used for comparison.

3.2. Acoustic data

The means of the f_0, F_1, F_2, F_3 (in Hz and Bark) values for short vowels are shown in Table 4. When the f_0, F_1, F_2, F_3 values of the sustained and short vowels were compared, the differences were found to be statistically insignificant. When the $F_3 - F_2$ values of the short vowels that indicate their backness were compared with each other, the differences were found to be statistically significant ($p < 0.05$), except between HUTV and [ϵ]. When the $F_1 - f_0$ values of the vowels that indicate their height were compared with each other, the differences between

Table 4
The means of the fundamental frequencies (f_0), first (F_1), second (F_2) and third (F_3) formants in Hz and their Bark transformed values for the short (natural) vowels

Vowels	f_0		F_1		F_2		F_3	
	Hz	Bark	Hz	Bark	Hz	Bark	Hz	Bark
ɑ	132	1.16	664	6.25	1081	9.00	2577	14.70
ϵ	131	1.15	526	5.14	1772	12.12	2525	14.56
HUTV	145	1.32	355	3.58	1482	11.01	2405	14.24
i	151	1.39	278	2.80	2275	13.87	2570	14.68
u	149	1.36	295	2.98	786	7.14	2226	13.73

HUTV and other vowels were found to be statistically significant ($p < 0.05$).

The fundamental frequencies and formant values of the vowels [ɨ], [ɯ] and [ɤ] uttered by the phoneticians are seen in Table 5. The representation of HUTV, [ɨ], [ɯ] and [ɤ] on acoustic vowel space is seen in Fig. 4. When the $F_1 - f_0$ and $F_3 - F_2$ values of these vowels and HUTV's were compared with each other, statistically significant differences were not found for all comparisons.

The Euclidian distances between HUTV and the vowels [ɨ], [ɯ], [ɤ] in vowel space were measured as 0.9, 0.9 and 0.8 Bark; the distances between [ɨ] and [ɯ], [ɨ] and [ɤ], [ɯ] and [ɤ] were measured as 1.7, 1.7 and 0.6 Bark, respectively.

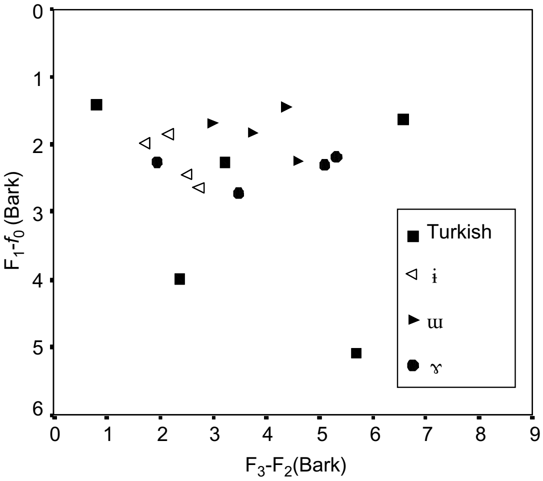

Fig. 4. Turkish vowels and HUTV-like IPA vowels in the acoustic vowel space. The vowels [i], [ϵ], [ɑ] and [u] are at margins. HUTV lies at the center, and can be compared with the vowels [ɨ], [ɯ] and [ɤ] uttered by four phoneticians.

3.3. Auditory data

Eighteen of the 220 synthetic stimuli were perceived as HUTV by all of the subjects. Fig. 5 shows all of the synthetic stimuli that were perceived as HUTV in acoustic vowel space. Although the stimuli were synthesized along with F_1 and F_2, the identifications were plotted on a two-dimensional $F_1 - f_0$ and $F_3 - F_2$ plane similar to acoustic vowel space for comparative reasons. The means of F_1 and F_2 values of the 18 stimuli were 358 Hz (SD, 62.4 Hz) and 1256 Hz (SD, 146.4 Hz); the $F_1 - f_0$ and $F_3 - F_2$ values were calculated as 2.3 Bark and 6.2 Bark, respectively. The Euclidian

Table 5
The fundamental frequencies (f_0), first (F_1), second (F_2) and third (F_3) formants values of the phoneticians' vowel, [ɨ], [ɯ] and [ɤ] (in Hz)

Phoneticians	[ɨ]				[ɯ]				[ɤ]			
	f_0	F_1	F_2	F_3	f_0	F_1	F_2	F_3	f_0	F_1	F_2	F_3
Esling	147	315	1927	2675	145	297	1690	2642	123	328	1790	2391
O'Grady	115	276	1409	2472	100	319	1678	2451	96	341	1459	2463
House*	177	434	2172	3304	182	397	1611	3220	214	444	1474	3190
Wells	136	316	1902	2462	146	277	1153	2240	140	342	1092	2452

* Female.

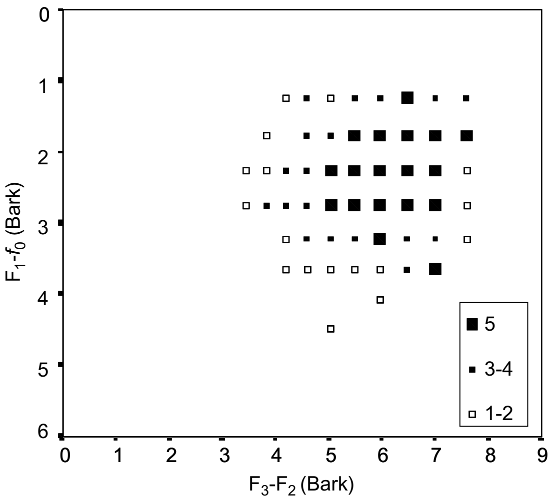

Fig. 5. The synthetic stimuli that were perceived as HUTV. Large filled squares show the stimuli that were perceived as HUTV by all of the five subjects, small filled squares show the ones that were perceived as HUTV by three or four of the subjects and small unfilled squares show the ones that were perceived as HUTV by one or two of the subjects.

distance between auditory and acoustic HUTVs was calculated as 4.0 Bark. When the $F_1 - f_0$ and $F_3 - F_2$ values auditory and acoustic HUTVs were compared, the difference between $F_1 - f_0$ values was not statistically significant, but the difference between $F_3 - F_2$ values were statistically significant ($p < 0.05$).

The numbers of invalid stimuli that the subjects responded to as inconsistent or unnatural, varied between 32 and 57 (mean, 43; SD, 12.1). When these stimuli were examined in detail, it was seen that the most frequent inconsistent pairs were /ɛ/-/œ/, /ɛ/-0 and HUTV-/u/.

During the auditory analysis performed by using IPA vowels, it was seen that the [ɯ] and [ɨ] vowels were perceived as HUTV by all of the subjects, the [ɤ] vowel by four of five subjects, and the [ə] vowel by one subject.

4. Discussion

HUTV is the most problematic vowel phoneme of Turkish for both Turkish children who acquire Turkish as a first language, and people who acquire this as a second language, because it is the least stable and the shortest vowel of Turkish. HUTV's representation in the Turkish alphabet is also confusing for speakers of languages using the Latin alphabet. Although the upper case *I* is dotless and lower case *i* is dotted, the dot is a distinguisher in Turkish, and the upper case *I* and the dotless lower case *ı* are used for HUTV, and the dotted upper case *İ* and the lower case *i* are used for the vowel /i/.

Even though the phonologic structure of Turkish suggests that HUTV is phonologically a back vowel, there is a disagreement among native Turkish linguists about its backness. Demircan (1979) and Demirezen (1986) accept it as a back vowel, Ergenç (1989) and Selen (1979) as a central one. The disagreement and indefiniteness about HUTV's backness, also exists in international publications. Kornfilt (1997) and Zimmer and Orgun (1999) accept HUTV as a back vowel and use ɯ to symbolize it. Esling (1994) accepts HUTV as a central vowel and uses ɨ as symbol.

For these reasons, we wanted to investigate the phonetic properties of this vowel using articulatory, acoustic and auditory analysis techniques that were outlined in Section 2.

For articulatory analysis of vowels, MRI has been used in many researches. Baer et al. (1991) investigated the vocal tract shape during articulation of the American English vowels and demonstrated 3-D reconstructions of the vocal tract. Whalen et al. (1999) examined English vowels by MRI. These authors used only midsagittal images and claimed obtaining full volumetric data which was much more time-consuming. Moore (1992) investigated three vowels and two continuants by using coronal and sagittal MRIs. Demolin et al. (2002) examined the position of articulators for five vowels by real-time MRI. However, we have not encountered any research that investigates a high unrounded mid or back vowel by MRI or other imaging techniques, and so we investigated five Turkish vowels including HUTV by using midsagittal MRI sections as Whalen et al. (1999) suggested. Sample MRIs can be seen in Fig. 3, and the vocal tract area functions for HUTV can be seen in Fig. 6. The analyses of the measurements on MRIs revealed that HUTV was similar to [u]

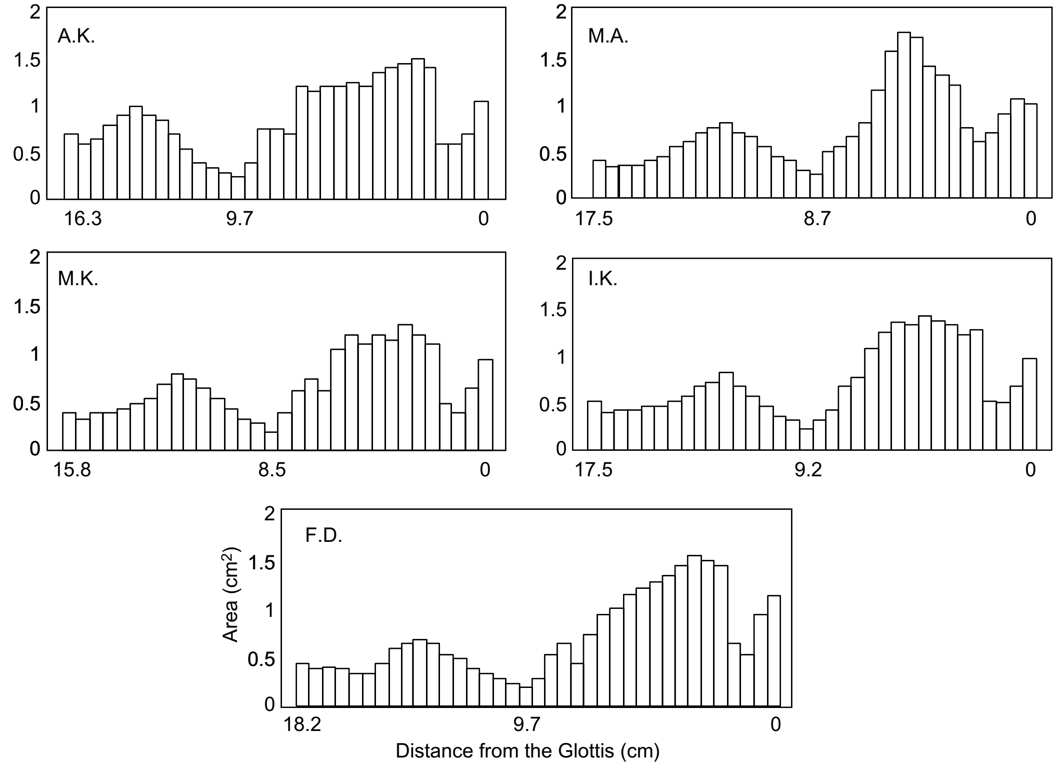

Fig. 6. The vocal tract area functions of HUTV for the five subjects.

and [ɛ] vowels, and suggested that its backness was between mid and back.

Investigations of vocal tract shape and acoustic properties of vowels are important for both speech production research and speech pathology. Because of ambiguity of phoneme boundaries of vowels, unlike consonants, and variations in these boundaries in different languages, the investigation of vowels in every language is necessary. Also, reliable normative data, that is beneficial for clinical decision making, may be gathered in such investigations. Selen (1979) investigated Turkish vowels for one male and one female subject by using spectrographic analysis. She suggested that HUTV is a central vowel or perhaps schwa. Selen (1979) defined F_1 and F_2 of HUTV as 320 and 2000 Hz, respectively, regardless of the subject's sex. The second formant's value seemed very high as compared with the value found in our study. Ergenç (1989) calculated the formant values of Turkish vowel phonemes using spectrographic techniques. She reported three different values for F_1 and F_2 of HUTV according to its position in the syllable. When the means of the three different values were calculated, F_1 and F_2 values of HUTV were found as 360 and 1453 Hz, respectively. We found, F_1 and F_2 values of HUTV as 355 and 1482 Hz, and these values were very close to her results. On the basis of her results, Ergenç (1989) claimed that HUTV was a central vowel. We think these two authors considered this matter only from a phonetic point of view, and also did not take into account the presentation problem of high unrounded vowels in the vowel space that will be mentioned below.

Auditory analysis performed by using synthetic stimuli revealed that auditory HUTV was more back than the acoustic one. This was due to hyperspace effect, as Johnson et al. (1993) mentioned. In the other part of the auditory analysis, results suggested that the subarea of HUTV in auditory vowel space was wide enough to involve the [ɨ], [ɯ] and [ɤ] vowels.

The articulatory and acoustic similarities between HUTV and the [ϵ] vowel were unexpected findings, in this study. Although this similarity seems unusual, in fact, it can originate from the factors that draw the upper right and lower left corners of the vowel space near each other. When a vowel comes close to the upper border of the vowel space, F_1 value will decrease because of increased pharyngeal volume, and when a vowel comes close to the left corner on the vowel space's upper border, F_2 value will increase due to decreasing of the oral volume, but, when a vowel comes close to the right corner, F_2 value will decrease due to increasing of the oral volume. Since further statistical analysis revealed that the differences of total vocal tract areas between vowels were not statistically significant in our study, we can accept the total vocal tract volume cannot expand, or decrease. In other words, when the pharyngeal volume increases, the oral volume decreases, and vice versa. For this reason, we hypothesize that both the upper right and lower left corners of the vowel space are influenced by opposite forces, so they become weakened leading to them coming closer to each other. On the contrary, the upper left and lower right corners are influenced by similar forces, so become strengthened leading to them to falling apart from each other. This relationship explains why articulatory and acoustic properties are close to the vowel [ϵ]. The situation of the vowel [u] is a bit different, since rounding of the lips increases volume of the oral cavity and makes it a more back vowel.

Our hypothesis is partly supported by Ladefoged (1993). According to him, removing lip rounding from the back vowel [u] to produce [ɯ] raises formant two, so that it would also be nearer to the center of a formant chart. Related to this issue, Catford (1977) also locates the [ɯ] vowel approximately at the mid point between vowels [i] and [u] on an acoustic vowel chart, without giving numerical data.

Acoustic properties and positions in the acoustic vowel space of back, unrounded vowels, unlike their rounded counterparts. Because F_2 values of unrounded vowels are lower than rounded ones, the shape of the acoustic vowel space that show the secondary cardinal vowels, does not look like the known shape of the vowel space. As clearly seen in Fig. 7, back unrounded vowels, specially high ones are close to center of the space, and seem like mid vowels. For this reason, the HUTV's location at the middle of the acoustic vowel chart does not imply it is a central vowel.

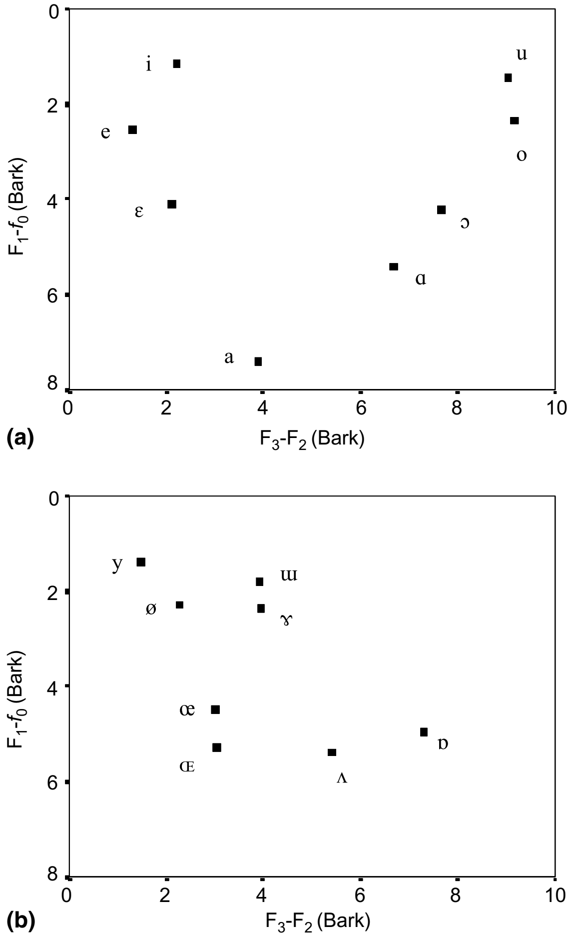

Fig. 7. Two acoustic vowel spaces: (a) was drawn based on the phoneticians' productions of the primary cardinal vowels, (b) of the secondary cardinal vowels.

5. Conclusion

HUTV is phonologically a high, back, unrounded vowel, because it contrasts with /ɑ/ in height, with /u/ in rounding, with /i/ in backness dimensions, so /ɯ/ symbol must be used in broad phonetic transcription. However, because of the instability of this vowel, various symbols like [ɯ], [ɨ], [ɤ] or [ə] may be used in narrow phonetic transcription. In order to achieve better understanding of the HUTV's acoustic and auditory properties, studies by using HUTV in context, are necessary.

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