Voice Onset Time for Turkish Stop Consonants in Adult Cochlear Implanted Patients

Abdullah Dalgic · Tolga Kandogan ·
Gokce Aksoy

Received: 3 August 2014 / Accepted: 14 October 2014 / Published online: 21 October 2014
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Abstract The voice onset time is a temporal acoustic parameter defined as the time between the release of the oral constriction for plosive production and the onset of vocal fold vibrations. Hearing impairment is one of the factors that can effect the magnitude of voice onset time. Since voice onset time is a useful, noninvasive method for documenting the articulatory–phonatory aspects of vocal training during speech, we investigated voice onset time values for Turkish stop consonants in adult cochlear implanted patients in order to clarify the effect of CI and sequential hearing rehabilitation over voice onset time values. The CI patients were divided into two groups according to duration of CI usage. We looked for relations between results of the study and average voice onset time values in Turkish language for adults. Mean VOT values for for both males and females in the first and second group are shown in Tables 1, 2, 3, and 4. Most syllables both in males and females statistically significant differ from average VOT values, e.g. They did not reach to normal hearing adults level. These acoustic results indicated that VOT may be an effective measure for examining the effect of cochlear implantation over the articulatory accuracy. As far as we know, this is the first publication using voice onset time values for the efficiency of cochlear implantation in adult patients.

Keywords Voice onset time · Cochlear implantation · Language

Introduction

The task of examining the articulation of consonants during speech can be accomplished through temporal-acoustic measures. Voice onset time (VOT) has been established as an important acoustic measure used to distinguish voiced from voiceless stop consonants across a variety of languages [1, 2].

VOT also serves as an inferential estimate of speech motor control, requiring fine motor coordination of the respiratory, phonatory, and articulatory structures [3].

VOT is a temporal acoustic parameter defined as the time between the release of the oral constriction for plosive production and the onset of vocal fold vibrations [4]. Measurements of VOT before the release are stated as negative numbers and called voicing lead, while measurements of VOT after the release are stated as positive numbers and called voicing lag. If release and voicing are simultaneous, VOT is zero [4]. Negative VOT scores represent vocal fold vibration before the release of the oral constriction and are associated with the term pre-voicing. Zero VOT represents the initiation of the vocal fold vibration simultaneous to the release of the oral constriction. Finally, positive VOT is associated with the onset of vocal fold vibration after the release of oral constriction [2]. It is believed that VOT is effective indicator of subtle articulatory-phonatory interaction differences in speech production [2].

Factors that can effect the magnitude of VOT include physiological differences (such as age, lung volume, vocal fold tension), pathological status (hearing impairment, depression), and different linguistic tasks (speech task, speech rate, phoneme environment [4, 5].

A. Dalgic (✉) · G. Aksoy
Department of Otolaryngology, Head and Neck Surgery, Izmir
Bozyaka Research and Training Hospital, Saim Cikrikci Cad.
No: 59 Bozyaka, 35170 Izmir, Turkey
e-mail: dalgicabdullah@gmail.com

T. Kandogan
Department of Otolaryngology, Head and Neck Surgery, Izmir
Tepecik Research and Training Hospital, Izmir, Turkey

The stop consonants in Turkish may be classified into three groups according to the place of their articulation: bilabials (p/, b/), dentals (t/, d/) and velars (k/, g/). For each group, it has two different types according to the manner of articulation: voiced and voiceless [4].

Since VOT is a useful, noninvasive method for documenting the articulatory–phonatory aspects of vocal training during speech, we investigated VOT values for Turkish stop consonants in adult cochlear implanted patients in order to clarify the effect of CI and sequential hearing rehabilitation over VOT values. We also looked for relations between results of the study and average VOT values in Turkish language for adults.

Material and Method

Subjects

Our subjects were 15 male and 11 female monolingual native Turkish speaking cochlear implanted volunteers using a general Turkish dialect. Their ages ranged from 18 to 48 years. (Mean 34) All of the subjects are at least 10 year-total hearing impaired at the time of cochlear implantation. The CI patients were divided into two groups according to duration of CI usage i.e., less than 4 years and more than 4 years, in order to clarify the effect of CI and sequential hearing rehabilitation over VOT values. Group 1 (less than 4 year usage) consisted of seven males and six females and group 2 consisted of eight males and five females.

Speech Stimuli

Each speaker uttered the following isolated syllables, which were written on papers, (the six Turkish stops i.e., /p/, /t/, /k/, /b/, /d/, /g/ combined with the eight Turkish vowels i.e., /a/, /e/, /o/, /i/, /ɔ/, /æ/, /u/, /y/) once in single syllable words in a carrier sentence (according to but modified from Ogut F. et al. [4]).

Recording Procedure

Subjects' utterances were recorded using a microphone and a PC with sound card. The microphone-mouth distance was constant at 15 cm. Each syllable was saved at 11,025 Hz sampling rate and at 16-bit resolution. For recording and analysis Multi-Speech (Kay Elemetrics, Model 4400) program was used.

The measurements were done on wideband spectrograms according to the procedure recommended by Lisker and Abramson [6]. The recorded signals were pre-emphasized (0.8 pre-emphasis level) in order to emphasize the high frequency components, which normally contain much less energy than the lower frequency components. The measurement on wideband spectrograms (215 Hz, Blackman window) was done in the following way: for the stops having negative VOT values, VOT was measured from the onset of low-amplitude periodic voicing to the onset of aperiodic burst activity, usually signaled by a sharp peak of somewhat higher amplitude. This duration is expressed as a negative number. For the stops having positive VOT values, they were measured from the first indication of initial aperiodic activity to the regular striation, and thus is a positive value [4].

Statistical Analysis

In the statistical analysis, Independent sample *t* test and Mann–Whitney *U* test was used. *P* < 0.05 is accepted as statistically significant.

Results

Mean VOT values for for both males and females in the first and second group are shown in Tables 1, 2, 3 and 4. Comparison of VOT values between groups for males and females and Comparison of average VOT values in two groups for both males and females are shown in Tables 5, 6, 7, 8, 9 and 10. In females, statistically significant

Table 1 Mean VOT values in the 1 group, females

		p	b—	t	d—	k	g—
/a/	F	35.8 ± 3.1	55.2 ± 1.5	48 ± 1.1	57 ± 3.5	63.3 ± 3.7	9.2 ± 2.8
/e/	F	34.7 ± 3.1	36 ± 3.5	43.3 ± 2.9	65 ± 4	71 ± 6	13.8 ± 3.4
/o/	F	43.8 ± 3.3	62.5 ± 3.2	57.8 ± 0.8	48.7 ± 6.8	69.5 ± 2.3	16.7 ± 1.6
/i/	F	51.3 ± 2.3	53.2 ± 8.7	60.3 ± 2	48.5 ± 4.5	75 ± 4.2	23.7 ± 2
/ɔ/	F	48.5 ± 4.8	56.8 ± 2.5	51.3 ± 4.3	62.5 ± 5.1	63.7 ± 5	9.3 ± 3.7
/æ/	F	47.7 ± 3.3	54.7 ± 4.9	45.2 ± 5.4	50.2 ± 4	64.5 ± 5.5	24.2 ± 2.9
/u/	F	55.5 ± 4.8	63.7 ± 3.1	54.5 ± 3.1	53.5 ± 5.1	67.2 ± 4.7	12.3 ± 1.5
/y/	F	57.3 ± 4.5	56.7 ± 2.9	54.7 ± 5.4	52.3 ± 2.5	71.7 ± 8.1	9.5 ± 1.4

Table 2 Mean VOT values in the 1 group, males

		p	b—	t	d—	k	g—
/ɑ/	M	26 ± 5.1	73.9 ± 3.8	45.7 ± 2	48.6 ± 5.4	63 ± 2	9.7 ± 2.1
/ɛ/	M	24.6 ± 4.2	81.1 ± 4.9	38.1 ± 3.2	55.9 ± 4.7	68.1 ± 3.8	5.1 ± 2.2
/ɔ/	M	33.4 ± 2.2	73.1 ± 17.8	52.6 ± 4.4	52.9 ± 2.7	70.4 ± 6.2	12.1 ± 1.7
/i/	M	37.7 ± 2.9	64.7 ± 3.4	55.9 ± 7.3	53.6 ± 2.7	71 ± 2.9	24.3 ± 1.7
/ɔ/	M	35.6 ± 3.8	75 ± 3.2	45.6 ± 3.3	61.6 ± 4.1	60.7 ± 1.3	9.7 ± 2.5
/æ/	M	32.4 ± 5.5	86.4 ± 5.3	48.3 ± 7	53.3 ± 6.4	65 ± 2.6	13.7 ± 3
/u/	M	40.6 ± 2.9	75.1 ± 2.7	54.7 ± 2.2	57 ± 2.2	71.1 ± 6.4	23.4 ± 2.6
/y/	M	45.4 ± 2.5	72.7 ± 5.4	53.7 ± 3.1	54 ± 3.6	75.7 ± 3.9	8.7 ± 1.7

Table 3 Mean VOT values in the 2 group, females

		p	b—	t	d—	k	g—
/ɑ/	F	39.2 ± 8.5	54.8 ± 4.3	50.2 ± 1.1	55.8 ± 2.3	63.2 ± 2.4	9.6 ± 3.3
/ɛ/	F	39 ± 6.8	38.2 ± 2.6	43.8 ± 1.8	66.6 ± 1.1	67.4 ± 4.1	17 ± 2.4
/ɔ/	F	42.4 ± 3.8	59 ± 2.3	59.8 ± 4.1	50 ± 2.8	66.2 ± 5.5	14.4 ± 2.9
/i/	F	48.4 ± 2.4	53.4 ± 2.5	55.8 ± 4.2	48.8 ± 4.5	68.6 ± 5.8	22.8 ± 1.9
/ɔ/	F	51 ± 3.2	54.4 ± 2.2	50.4 ± 6.5	60.6 ± 1.8	65.6 ± 2.3	10 ± 1.2
/æ/	F	48.2 ± 5.8	49.2 ± 2.2	50.6 ± 5.3	49.8 ± 5.2	66.6 ± 3.8	23.6 ± 3.3
/u/	F	54.6 ± 3.9	59.8 ± 7.3	55.8 ± 5.1	52.6 ± 2.5	67 ± 7	13 ± 2.1
/y/	F	60.2 ± 1.9	65 ± 5.4	58.4 ± 1.9	49.2 ± 2.5	73 ± 3.5	9.8 ± 0.8

Table 4 Mean VOT values in the 2 group, males

		p	b—	t	d—	k	g—
/ɑ/	M	27 ± 6.5	74.6 ± 3.1	47.1 ± 2.6	51.6 ± 3.4	65.1 ± 1.6	8.3 ± 3
/ɛ/	M	28.8 ± 3.0	80.5 ± 4.1	37.3 ± 2.7	62.4 ± 4.1	66.0 ± 4.4	4.6 ± 1.7
/ɔ/	M	33.4 ± 2.5	82 ± 3.5	55.5 ± 2.1	51.5 ± 6.7	66.9 ± 3.7	11.6 ± 2.2
/i/	M	42.6 ± 1.4	67.4 ± 2.7	57.3 ± 4.2	56.5 ± 1.6	73.5 ± 3.9	24.6 ± 2.5
/ɔ/	M	35.6 ± 3.9	72.8 ± 3	47.3 ± 3	61.9 ± 2.7	61.3 ± 0.5	8.9 ± 1.8
/æ/	M	37.4 ± 3.3	89 ± 2.3	48.4 ± 6.1	53.6 ± 5	64.5 ± 2.7	15.3 ± 2.5
/u/	M	43.6 ± 6.2	77.8 ± 3	54.3 ± 4	54.6 ± 4.5	73.4 ± 2.2	24.8 ± 2.9
/y/	M	46.6 ± 3.3	75.8 ± 3.1	53.6 ± 3.9	54.5 ± 4.7	75.8 ± 5	7.9 ± 1.8

difference was found in /tɑ/ sound between two groups. In males, statistically significant difference was found in /pɛ/, /pi/, /bi/, /dɛ/ sounds between two groups. Statistically significant difference was found in /pæ/, /dæ/, /gæ/, /bɑ/, /tɑ/, /dɑ/, /bɔ/, /tɔ/, /gɔ/, /ti/, /gi/, /tɔ/, /tu/, /gu/, /ty/, /ky/, /gy/ sounds between females in group 1 and normal female values. Statistically significant difference was found in /tɑ/, /dɑ/, /kɑ/, /dɛ/, /bɔ/, /bi/, /gi/, /dɔ/, /kɔ/, /gɔ/, /pæ/, /gæ/, /gu/, /ty/, /ky/, /gy/ sounds between females in group 2 and normal female values. There was a statistically significant difference in /tɑ/, /pɛ/, /gɛ/, /pɔ/, /gɔ/, /ki/, /ki/, /gi/, /bɔ/, /tɔ/, /kɔ/, /bæ/, /kæ/, /pu/, /bu/, /py/, /gy/ sounds between males in group 1 and normal male values. There was a statistically significant difference in /pɛ/, /dɛ/, /pi/, /bi/ sounds between males in group 2 and normal male values.

Discussion

VOT is usually measured from wideband spectrograms according to the procedure recommended by Lisker and Abramson [6]. It is measured from the onset of the energy ‘burst’ corresponding to the release of an articulatory constriction to the first of the regularly spaced vertical striations of the vocal fold vibrations [4].

VOT has been used to examine the articulatory differences across languages, genders, and motor speech impairments [5]. The control of acoustic cues to voicing requires a critically timed coordination of respiratory, phonatory and articulatory movements, so it presents a particularly challenging contrast for acquisition and for experimental analysis [1].

Table 5 Comparison of VOT values between group 1 and 2 in females

		p	b—	t	d—	k	g—
/ɑ/	F	—	—	+	—	—	—
/ɛ/	F	—	—	—	—	—	—
/ɔ/	F	—	—	—	—	—	—
/i/	F	—	—	—	—	—	—
/ɔ/	F	—	—	—	—	—	—
/æ/	F	—	—	—	—	—	—
/u/	F	—	—	—	—	—	—
/y/	F	—	—	—	—	—	—

Positive sign indicates statistically significance

Table 6 Comparison of VOT values between group 1 and 2 in males

		p	b—	t	d—	k	g—
/ɑ/	M	—	—	—	—	—	—
/ɛ/	M	+	—	—	+	—	—
/ɔ/	M	—	—	—	—	—	—
/i/	M	+	+	—	—	—	—
/ɔ/	M	—	—	—	—	—	—
/æ/	M	—	—	—	—	—	—
/u/	M	—	—	—	—	—	—
/y/	M	—	—	—	—	—	—

Positive sign indicates statistically significance

Table 7 Comparison of average VOT values with group 1 females

		p	b—	t	d—	k	g—
/ɑ/	F	—	+	+	+	—	—
/ɛ/	F	—	—	—	—	—	—
/ɔ/	F	—	+	+	—	—	+
/i/	F	—	—	+	—	—	+
/ɔ/	F	—	—	+	—	—	—
/æ/	F	+	—	—	+	—	+
/u/	F	—	—	+	—	—	+
/y/	F	—	—	+	—	+	+

Positive sign indicates statistically significance

Table 8 Comparison of average VOT values with group 2 females

		p	b—	t	d—	k	g—
/ɑ/	F	—	—	+	+	+	—
/ɛ/	F	—	—	—	+	—	—
/ɔ/	F	—	+	—	—	—	—
/i/	F	—	+	—	—	—	+
/ɔ/	F	—	—	—	+	+	+
/æ/	F	+	—	—	—	—	+
/u/	F	—	—	—	—	—	+
/y/	F	—	—	+	—	+	+

Positive sign indicates statistically significance

Table 9 Comparison of average VOT values with group 1 males

		p	b–	t	d–	k	g–
/ɑ/	M	–	–	+	–	–	–
/ɛ/	M	+	–	–	–	–	+
/ɔ/	M	+	–	–	+	–	–
/i/	M	+	–	–	–	+	+
/ɔ/	M	–	+	+	–	+	–
/æ/	M	–	+	–	–	+	–
/u/	M	+	+	–	–	–	–
/y/	M	+	–	–	–	–	+

Positive sign indicates statistically significance

Table 10 Comparison of average VOT values with group 2 males

		p	b–	t	d–	k	g–
/ɑ/	M	–	–	+	–	+	–
/ɛ/	M	+	+	–	–	–	+
/ɔ/	M	+	–	–	–	–	–
/i/	M	–	+	–	+	+	+
/ɔ/	M	+	+	+	–	+	–
/æ/	M	+	+	–	–	+	–
/u/	M	–	+	–	–	–	–
/y/	M	+	+	–	–	–	+

Positive sign indicates statistically significance

Finally, anomalies in the voicing contrast of adventitiously deaf adults can throw light on the role of hearing when it is present [1].

VOT is an effective indicator of subtle articulatory–phonatory interaction differences in speech production and it may prove an effective measure for physiologic differences between trained singers and nonsingers. As such, it may be a useful, noninvasive method for documenting the articulatory–phonatory aspects of vocal training during both speech and singing [2].

The relation between partial or absent hearing and control of the voicing contrast is important. Speakers who are born deaf characteristically have great difficulty mastering that contrast, in part because the laryngeal gestures underlying it are not visible [1]. Postlingually deafened adults generally have had normal access to language models and to the sounds of their own voices. Thus they were able to develop phonemic representations as well as a neural model of relations between their motor commands and the resultant patterns of sound and somesthesia [1].

In some pathological voices, VOT cannot be measured. This can either be due to the impossibility to determine the location of the burst or the onset of regular striations on the spectrogram [7]. The burst does not occur when a subject fails to achieve full closure in the production of stop consonants. Similarly, in normal voices the vowel onset may be

difficult to determine [4]. Normal VOT values are different between languages like English, French, Italian, Spanish, Thai and Turkish and the standardization must be made for all of the languages. For Turkish adult speakers the VOT values of /p/, /t/, /k/, /b/, /d/, /g/ were found to be 40, 49, 69, –65, –52, and –9 respectively [4].

In Turkish language the voiceless plosives have positive VOT values as in all other languages. The VOT value of /k/ is the longest in all of the languages. In the voiced plosives, the VOT values are negatives except for English. The VOT values for /b/ and /d/ are close to each other in all of the languages. Also, the VOT value of /g/ is close to the VOT values of /b/ and /d/ in English, French, Italian, and Spanish when compared in each language, but it differs a lot in Turkish. In Turkish, we obtained positive VOT values of /g/ in 12 (40 %) and negative values in 18 (60 %) of our cases [1]. Ogut et al. also found that sex has no main effect on VOT values [4].

The purpose of this study was to examine the effects of cochlear implantation and sequential hearing rehabilitation over the VOT values in time. We also looked for relations between results of the study and average VOT values in Turkish language for adults.

Although some statistically significant differences were found between the two groups in some syllables, both in males and females, which was accomplished through

cochlear implantation, e.g. direct stimulation of the auditory nerve, we believe, interesting results were obtained when the results of the study were compared with the average VOT values in Turkish language. Most syllables both in males and females statistically significant differ from average VOT values, e.g. They did not reach to normal hearing adults level.

Since VOT is an effective indicator of subtle articulatory–phonatory interaction differences in speech production and also is an effective measure for examining vocal tract adjustment, and serves as an inferential estimate of speech motor control, requiring fine motor coordination of the respiratory, phonatory, and articulatory structures [3], we may say that in time, cochlear implantation improved articulatory accuracy and fine motor coordination of the respiratory, phonatory, and articulatory structures through direct stimulation of the auditory nerve, but it can be suggested that in time it may not be possible that implantation will return the deviated mean VOT values to the normal levels, e.g. the articulatory accuracy may not be as same as the normal hearing people.

The adaptation of the brain to new situations is called neuroplasticity. Through cochlear implantation, direct stimulation of auditory nerve is provided. The developed neuronal activity in brain through cochlear implantation improved temporal-acoustic measures, but not to the normal levels (Stephane [8]).

Conclusion

These acoustic results indicated that VOT may be an effective measure for examining the effect of cochlear implantation over the articulatory accuracy. Cochlear implantation improved articulatory accuracy and fine

motor coordination of the phonatory and articulatory structures through direct stimulation of the auditory nerve, but articulatory accuracy may not be as same as the normal hearing people in time. These results may also be a pioneer for future investigations in finding a correlation between physiologic vocal tract adjustments during speech and temporal-acoustic measures of cochlear implant users.

Acknowledgments This study has no financial support from any sources.

Conflict of Interest None.

References

1. Lane H, Perkell JS (2005) Control of voice-onset time in the absence of hearing: a review. *J Speech Lang Hear Res* 48(6): 1334–1343
2. McCrea CR, Morris RJ (2007) Effects of vocal training and phonatory task on voice onset time. *J Voice* 21(1):54–63
3. Robb M, Gilbert H, Lerman J (2005) Influence of gender and environmental setting on voice onset time. *Folia Phoniatr Logop* 57(3):125–133
4. Ogut F, Kilic MA, Engin EZ, Midilli R (2006) Voice onset time for Turkish stop consonants. *Speech Commun* 48:1094–1099
5. McCrea CR, Morris RJ (2005) The effects of fundamental frequency level on voice onset time in normal adult male speakers. *J Speech Lang Hear Res* 48(5):1013–1024
6. Lisker L, Abramson AS (1964) A cross-language study of voicing in initial stops: acoustical measurements. *Word* 20:384–422
7. Ozsancak C, Auzou P, Mary J, Hannequin D (2001) Measurement of voice onset time in dysarthric patients: methodological considerations. *Folia Phoniatrica et Logop* 53:48–57
8. Roman Stephane, Canevet Georges, Lorenzi Christian, Triglia Jean-Michel, Liegeois-Chauvel Catherine (2004) Voice onset time encoding in patients with left and right cochlear implants. *Neuroreport* 15(4):601–605