Study of Acoustic Correlates of English Lexical Stress Produced by Native (L1) Bengali Speakers Compared to Native (L1) English Speakers

Shambhu Nath Saha, Shyamal Kr. Das Mandal

Centre for Educational Technology, Indian Institute of Technology, Kharagpur, India

shambhuju@gmail.com, sdasmandal@cet.iitkgp.ernet.in

10.21437/Interspeech.2015-257

Abstract

English lexical stress is multidimensional in nature and acoustically related to combination of fundamental frequency (F0), duration, intensity and vowel quality. Errors in any or all of these correlates could interfere with perception of the stress contrast, but it is unknown which correlates are most difficult for Bengali speakers to acquire. This study compares the use of these correlates in the production of English lexical stress contrasts by 10 L1 English and 20 L1 Bengali speakers. Results showed that although Bengali speakers used all four acoustic correlates in similar manner like English speakers, but they produced significantly less native like stress patterns. English speakers reduced vowel duration significantly more in the unstressed vowels compared to Bengali speakers and degree of intensity and F0 increase in stressed vowels by English speakers was higher than that by Bengali speakers. There were also significant differences in formant patterns across speaker groups, such that Bengali speakers produced English like vowel reduction in certain unstressed syllables, but in other cases Bengali speakers have tendency to either not reduce or incorrectly reduce vowels in unstressed syllables. Results suggest that Bengali speakers' production of English lexical stress contrast is influenced by L1 language experience and L1 phonology.

Index Terms: acoustic correlates, lexical stress contrasts, phonology, reliable cue, vowel quality, vowel reduction

1. Introduction

English continues to grow in importance as a language for international communication throughout the world. English is also being studied and spoken as a second language in more countries than ever before. Thus, a comprehensive understanding of the variation present in the dialects of English spoken in the world today is a fundamental issue for the development of English language education as well as spoken language science and technology. Asia is home to the largest number of English learners and speakers in the world. In India, combining L1 and nonnative (L2) speakers, more people speak or understand English than any other country in the world. Thus research on spoken English of Indian speakers from a multidisciplinary perspective is urgently needed. Therefore it is necessary to collect L2 English speech from as many regions of India as possible and compare with L1 English speech based on segmental and supra segmental aspects in order to derive a set of core properties common to all varieties of English spoken by Indian speakers. From the theory of second language acquisition, it is suggested that proper acquisition involves in correct production and perception of one of the most important suprasegmental features that is lexical stress. English is a stress-accent language [1] and English lexical stress is contrastive in nature and related to part-of-speech where English disyllabic words in which the location of stress on first or second syllable led the word to be identified as a noun or a verb respectively [2]. Acoustic correlates of duration, intensity, pitch, vowel quality are associated with the perception and production of English lexical stress where stressed syllables have higher pitch, greater intensity and longer duration than unstressed syllables [3], [4], and [5].In English, degree of increase in intensity of stressed vowels is greater than that of F0 [6] and intensity is more reliable cue for stress than F0 [7]. Unlike English, word stress placement in Bengali is restricted to the initial syllable of a word [8] and is not contrastive in nature [9]. Bengali lexical stress is expressed by a combination of pitch, duration and intensity, but stress does not affect vowel quality in Bengali [10]. Although F0, intensity, duration serve as cues to lexical stress in Bengali, the stress in a word is dominantly realized by a fall in the F0 from a high pitched syllable to the following syllable [8], and there is very little use of intensity to identify stress in Bengali [11].

Previous studies [12] and [13] reveal that L2 learners need to acquire language specific aspects of stress to approximate L1 like production in L2. However, unless a speaker becomes familiar with the stress patterns of the target language, it would be difficult to produce stress patterns of that language appropriately. In that case L1 prosody may influence on L2, results in language interference. This interference of L1 phonetics and phonology on the acquisition of L2 stress pattern causes difficulties to produce and perceive correctly the specific acoustic cue patterns related to L2 stress [13] , [14], and [15]. The objective of this study is to investigate the production of English lexical stress by L1 Bengali speakers having fluency in English to determine which acoustic features of English lexical stress are difficult for them to acquire. In order to do that, examine the differences between L1 and L2 (L1 Bengali) English speakers in terms of their use of acoustic correlates of English lexical stress under the conditions in which speakers were clearly aware of proper location of stress.

2. Method

2.1. Speakers

In this study, ten L1 American English speakers (5 male, 5 female) and twenty L1 Bengali speakers (8 male, 12 female) with native language Standard Colloquial Bengali (SCB) were participated. English participants ranged in age from 21 to 28 years of age, while L1 Bengali speakers were in the age group between 20 to 35 years. English speakers were all native residents of the United States (U.S) and students of Purdue

University, while the Bengali speakers were all originally from Kolkata in West Bengal and had either completed undergraduate degree studies or were continuing their postgraduate studies. Moreover the L1 Bengali speakers had studied English as a second language for a minimum of ten years and were fluent in English.

2.2. Materials and procedure

Seven pairs of disyllabic words given in Table 1 were selected following the methodology of Beckman [1] and Fry [2], [16]. Each word pair consisted of a noun and a verb that had identical spelling forms and differed only in terms of stress placement. The words were randomly presented and were pronounced two times each by L1 English speakers and three times each by L1 Bengali speakers at their normal speech rate in the neutral frame sentence '*I said test word this time*'. The stressed syllable was marked on the reading text for both English and Bengali speakers. The speech was recorded by using AESOP's [17] recording tool kit with AESOP's specified recording platform. For the fluency of reading, the speakers were instructed to read out the text several times before recording and read the material aloud. The speech was digitized at a sampling rate 16 kHz with an accuracy of 16 bits/sample. Using Praat acoustic analysis software, stressed and unstressed vowels of each test word were examined acoustically for duration; the average, peak and lowest F0; average and peak intensity; and first (F1) and second formant (F2) frequencies. The statistical analysis was done by SPSS where two way mixed factorial analysis of variance (ANOVA) was performed with native language as between subjects variable and stress position (1st syllable or 2nd syllable) as the within subjects variable for the originally measured values of each acoustic variable. All post-hoc tests (LSD) were performed with p value of 0.05.

Table 1. *Disyllabic words with contrasting stress positions.*

Noun	IPA Notation	Verb	IPA Notation
`contract	`kɑ:ntrækt	con`tract	kən`trækt
`desert	`dezəɹt	de`sert	dI`zəɹt
`object	`abʤekt	ob`ject	əb`ʤekt
`permit	`pɝmIt	per`mit	pəɹ`mIt
`rebel	`rebəl	re`bel	rI`bel
`record	`rekərd	re`cord	rI`kɔ:rd
`subject	`sʌbʤekt	sub`ject	səb`ʤekt

3. Results

3.1. Duration

In this study, durations of first syllable's vowel (V1) and second syllable's vowel (V2) of each test word were measured (in ms) and the results are shown in Table 2 and Table 3. From these results, it is observed that stressed vowels were longer than unstressed vowels for both L1 English and L1 Bengali speakers. There was significant main effect of stress position [for V1: $F(1, 28) = 563.38$, $p < 0.001$; for V2: $F(1, 28) = 325.94$, $p < 0.001$], but no effect of language [for V1: $F(1, 28) = 1.8$, $p > 0.05$; for V2: $F(1, 28) = 0.000011$, $p > 0.05$] on vowel duration. However there was significant interaction between language groups and stress position [for V1: $F(1, 28) = 61.14$, $p < 0.001$; for V2: $F(1, 28) = 26.19$, $p < 0.001$] on the vowel duration. The result of this analysis implies that for both language groups there was significant difference between duration of stressed vowel and its unstressed counterpart.

Table 2. *Average duration of V1 (ms) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
98.03	55.61	92.71	71.31

Table 3. *Average duration of V2 (ms) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
64.21	109.41	74.18	99.42

The interaction effect and post-hoc test (based on language group) showed that, stressed V1 was longer than unstressed V1 [L1 English: $p = 0.000000099$, $p < 0.05$; L1 Bengali: $p = 0.000000053$, $p < 0.05$] and stressed V2 was longer than unstressed V2 [L1 English: $p = 0.000000026$, $p < 0.05$; L1 Bengali: $p = 0.000000074$, $p < 0.05$] for both speaker groups. From interaction effect and pos-hoc test (based on stress position), it is also observed that there was not statistically significant difference between duration of stressed vowel of both speaker groups [for V1: $p = 0.24$, $p > 0.05$; for V2: $p = 0.065$, $p > 0.05$], but duration of unstressed vowel was significantly differ between both speaker groups [for V1: $p = 0.00023$ $p < 0.05$; for V2: $p = 0.044$, $p < 0.05$]. This result implies that L1 English speakers reduced vowel duration significantly more than L1 Bengali speakers in unstressed vowels and there was a larger difference between duration of stressed and unstressed vowels in the L1 English speakers' utterances compared to L1 Bengali speakers' utterances.

3.2. Intensity

In this study, the peak and average intensity of all vowels were measured (in dB). The ratio between V1 and V2 vowels within the same word was obtained and results are shown in Table 4 and Table 5. These results show that V1/V2 ratios for both average and peak intensities of both speaker groups were over 100% when V1 was stressed and below 100% when V2 was stressed. This means that both language groups increased vowel intensity when vowels were stressed compared to unstressed vowels in the same word.

Table 4. *Average intensity ratio of V1/ V2 (%) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
112.38	92.68	105.05	94.62

Table 5. *Peak intensity ratio of V1/V2 (%) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
111.71	92.61	104.98	94.56

There were significant main effect of language group [for average intensity ratio: $F(1,28) = 8.56$, $p < 0.05$; for peak intensity ratio : $F(1,28) = 7.21$, $p < 0.05$], significant main effect of stress position [for average intensity ratio: $F(1,28) = 216.98$, $p < 0.001$; for peak intensity ratio : $F(1,28) = 217.14$, $p < 0.001$], as well as significant interaction between language

group and stress position [for average intensity ratio: $F(1,28) = 20.56$, $p < 0.001$; for peak intensity ratio : $F(1,28) = 18.82$, $p < 0.001$]. The interaction effect and post-hoc test (based on language group) showed that for both language groups, there was significant difference between average intensity ratio of V1/V2 [L1 English: $p = 0.0000000022$, $p < 0.05$; L1 Bengali: $p = 0.0000000014$, $p < 0.05$] as well as the peak intensity ratio of V1/V2 [L1 English: $p = 0.00000000039$, $p < 0.05$; L1 Bengali: $p = 0.0000000054$, $p < 0.05$] in differing stress locations. This means that V1/V2 ratio was significantly higher when V1 was stressed than V2 was stressed for both average intensity ratio as well as peak intensity ratio for both speaker groups. This result indicates that average and peak intensity of stressed vowel was higher than that of unstressed vowel in the same word for both speaker groups. It is also observed from interaction effect and pos-hoc test (based on stress position) that there was significant difference between average intensity ratio [$p = 0.000052$, $p < 0.05$] as well as peak intensity ratio [$p = 0.000089$, $p < 0.05$] of V1/V2 for both speaker groups when V1 was stressed, but there was no significant difference between average intensity ratio [$p = 0.117$, $p > 0.05$] as well as peak intensity ratio [$p = 0.113$, $p > 0.05$] of V1/V2 for both speaker groups when V2 was stressed. As a result there was a larger difference between average intensity and peak intensity ratio of V1/V2 respectively in differing stress locations for L1 English speakers compared to L2 English speakers. From this result, it is implied that both language groups increased vowel intensity more when vowels were stressed compared with unstressed vowels, but degree of intensity increase in stressed vowels by L1 English speakers was higher than that by L1 Bengali speakers in their speech.

3.3. Fundamental frequency (F0)

The average F0 of all vowels, peak F0 of stressed vowels and lowest F0 of unstressed vowels were measured for both language groups (in Hz). The ratio between stressed and unstressed vowels within the same word for average F0 and peak and lowest F0 was obtained and the results are shown in Table 6 and Table 7. From these results, it is observed that V1/V2 ratios were over 100% for average F0 and peak/lowest F0 when V1 or V2 was stressed for both language groups. This implies that when vowels were stressed their F0s were increased for both language groups.

Table 6. *Average F0 ratio of V1/V2 (%) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
128.09	103.56	117.4	109.65

Table 7. *Peak & lowest F0 ratio of V1/V2 (%) in differing stress locations.*

L1 English		L1 Bengali	
1st syllable stressed	2nd syllable stressed	1st syllable stressed	2nd syllable stressed
131.64	106.95	122.1	112.22

There was significant main effect of stress position [for average F0 ratio: $F(1,28) = 240.82$, $p < 0.001$; for peak F0/ lowest F0 ratio: $F(1,28) = 165.75$, $p < 0.001$], but no effect of language [for average F0 ratio: $F(1,28) = 3.62$, $p > 0.05$; for peak F0/ lowest F0 ratio : $F(1,28) = 3.12$, $p > 0.05$]. However there was a significant interaction between language group and stress position for the average F0 ratio [$F(1, 28) = 65.15$, $p < 0.001$] and for the peak-lowest F0 ratio [$F(1, 28) = 30.41$, $p < 0.001$]. The interaction effect and post-hoc test (based on language group) showed that, there was significant difference between average F0 ratio [L1 English: $p = 0.00000000167$, $p < 0.05$; L1 Bengali: $p = 0.000000551$, $p < 0.05$] as well as the ratio between peak and lowest F0s [L1 English: $p = 0.0000000066$, $p < 0.05$; L1 Bengali: $p = 0.00000067$, $p < 0.05$] in differing stress locations for both speaker groups. This means that V1/V2 ratio was significantly higher when V1 was stressed than V2 was stressed for average F0 ratio as well as peak and lowest F0 ratio for both speaker groups. This result indicates that the increase in F0 was less when V2 of each word was stressed compared to V1 was stressed. This was due to the natural declination of F0 in the simple declarative sentences in both language phonologies; as a result F0 is higher at the beginning of utterance and is gradually lowered towards the end of utterance. It is also observed from interaction effect and pos-hoc test (based on stress position) that V1/V2 ratio was significantly higher for both average F0 ratio and the ratio between peak and lowest F0s for L1 English speakers compared to L1 Bengali speakers when V1 was stressed [for average F0 ratio: $p = 0.00000068$, $p < 0.05$; for peak F0/lowest F0 ratio: $p = 0.0000064$, $p < 0.05$], but V1/V2 ratio was significantly lower for L1 English speakers than L2 English speakers when V2 was stressed [for average F0 ratio: $p = 0.00037$, $p < 0.05$; for peak F0/lowest F0 ratio: $p = 0.0096$, $p < 0.05$].This result indicates that although both speaker groups increased F0 of stressed vowels, the degree of F0 increase of stressed vowels was significantly higher for L1 English speakers compared to L1 Bengali speakers.

3.4. Vowel quality

Vowel quality is defined in terms of first (F1) and second (F2) formant frequencies. In American English, presence or absence of stress effects vowel quality, where vowels in unstressed syllables are reduced in quality,results in vowel reduction. Vowel quality is an important acoustic correlate of stress and failure to appropriately reduce unstressed vowels perceives the L2 accent. There are some novel measures to quantify degree of vowel reduction [18]. In this study formant spacing was used to quantify the property of vowel quality where two measures are derived from the center frequencies of F1 and F2 [19]. The compact-diffuse (C-D), calculated as the difference between F1 and F2 (F2-F1), is correlated with the phonetic property of tongue height. The grave-acute (G-A) feature, calculated as the arithmetic mean of F1 and F2 [(F1+F2)/2], is correlated with the phonetic dimension of the tongue advancement. The C-D measure is more indicative, because it denotes F2-F1, vowel centralization in the F1 and F2 plane, causes this value to approach that of the centroid [20]. For each syllable in each word, separate ANOVAs were performed for both C-D and G-A variables with two factors - language and stress position. Results of post-hoc test (LSD) at level $p < 0.05$ are shown in Table 8, where S refers to stressed syllables, U to unstressed syllables, AE to American English speakers' productions and B to Bengali speakers' productions. AE < B (AE > B) indicates that English speakers' productions of a given syllable have smaller (higher) mean values of a corresponding acoustic feature than did Bengali speakers'. Similarly S< U (S > U) indicates smaller (higher) mean values of a given acoustic feature for stressed syllable compared to that of unstressed syllable for corresponding language group.

Table 8. Results of pair wise comparisons between formant measures for stressed and unstressed vowels by syllable.

Syllable	Stressed / Unstressed				American English / Bengali			
	American English		Bengali		Stressed		Unstressed	
	C-D	G-A	C-D	G-A	C-D	G-A	C-D	G-A
con-	S < U		S < U		AE > B	AE > B	AE > B	AE > B
-tract		S > U		S > U				
de-	S < U	S > U			AE < B	AE < B	AE < B	AE < B
-sert	S < U	S < U	S < U	S < U	AE > B		AE > B	
ob-	S < U					AE > B	AE > B	AE > B
-ject		S > U	S < U	S > U	AE < B	AE < B	AE < B	AE < B
per-		S > U			AE > B		AE > B	
-mit	S > U			S > U	AE < B	AE < B	AE < B	AE < B
re-	S < U		S < U		AE < B	AE< B	AE < B	AE < B
-bel	S > U	S > U	S > U		AE < B		AE < B	AE < B
re-	S < U	S > U			AE < B	AE< B	AE < B	AE < B
-cord	S < U	S < U				AE < B	AE > B	AE < B
sub-	S < U	S > U	S < U		AE > B		AE > B	AE < B
-ject	S < U	S > U		S > U	AE < B	AE < B	AE < B	AE < B

From the result of analysis (shown in Table 8), it is observed that there were statistically significant difference between L1 English and L1 Bengali speakers in their production of stressed as well as unstressed syllables, and most of these differences appeared in (C-D) feature; only exception is for the syllable *-tract* of the word *contract* in which the stressed and unstressed versions did not show any significant difference between L1 English and L1 Bengali speakers in terms of both the C-D and G-A features. There are three patterns found from this analysis:

Type 1. Incorrect reduction: Both English and Bengali speakers showed significant differences between stressed and unstressed vowels, but the unstressed vowels produced by Bengali speakers was in each case significantly different (in terms of either C-D, G-A, or both) from unstressed vowels produced by English speakers. These syllables include: *con-* (*contract*), *-sert* (*desert*), *-ject* (*object*), *-mit* (*permit*), *re-* (*rebel*), *-bel* (*rebel*), *sub-* (*subject*), *-ject* (*subject*).

Type 2. Lack of reduction: Unlike English speakers, Bengali speakers did not show a significant change in either the C-D or G-A features from stressed to unstressed versions of the following syllables: *de-* (*desert*), *ob-* (*object*), *per-* (*permit*), *re-* (*record*), *-cord* (*record*).

Type 3. Correct reduction: The only syllable in which both American and Bengali speakers appear to show a similar degree and quality of vowel reduction is the syllable *-tract* (*contract*).

From this analysis of vowel reduction, it is observed that L1 Bengali speakers have difficulty to produce native like stressed or unstressed syllables in their English speech. In particular, for all vowels used in the stressed syllables except syllable *-tract* in *contract*, L1 Bengali speakers produced vowels that differ from L1 English speakers. In agreement with this observation, the difference between all Bengali and English stressed syllables except syllable *-tract* in *contract* was statistically significant (Table 8, fifth and sixth columns), which implies that L1 Bengali speakers have significant difficulty to produce American English full vowels in stressed syllables. Moreover L1 Bengali speakers have tendency to either not reduce or incorrectly reduce vowels in unstressed syllables.

4. Discussion and Conclusions

In this study, acoustic analysis indicates that L1 English and L1 Bengali speakers used the acoustic correlates of vowel duration, intensity and F0 in similar manner. Durations of unstressed vowels were significantly shorter than their stressed counterparts in the same words for both language groups, but L1 English speakers reduced vowel duration significantly more in the unstressed vowels compared to L1 Bengali speakers. Moreover both groups produced stressed vowels with a greater intensity, higher F0 than unstressed vowels, but degree of intensity as well as F0 increase in stressed vowels by L1 English speakers was higher than that by L1 Bengali speakers. Finally, there was a significant difference in vowel quality between L1 English and L1 Bengali speakers. L1 English speakers varied F1 and F2 values of target vowels depending on the presence or absence of stress, but stress had little effect on the vowel quality of the L1 Bengali speakers' English utterances. In the present study, L1 Bengali speakers' poor performance on vowel reduction appears due to inability to correctly produce reduced vowel in unstressed syllable and full vowel in stressed syllable. This difference contributed significantly to the perception of non nativeness in the production of English stress contrast by L1 Bengali speakers.

From these results, it appears that L1 Bengali speakers are more sensitive to F0 to mark English lexical stress compared to intensity which is phonologically important in Bengali, because Bengali lexical stress is indicated mainly by F0 change. In conclusion, although L1 Bengali speakers are able to control duration, intensity, F0 in an English like manner to signal lexical stress, they are not able to manage vowel quality in a strictly English like manner due to interference from their native phonology and native language experience. Since L1 Bengali speakers were able to achieve good control of duration, intensity, F0, and to a limited extent vowel quality of stressed and unstressed vowels in English, it is difficult to determine whether they learned to produce these cues systematically, whether they have already learned these cues for the specific words examined here to achieve native like patterns in the L2. Further research is needed to examine the observed non native like vowel quality as well as the relative contribution of the various cues examined in this study to the perception of stress in English.

5. References

[1] M.E. Beckman, *Stress and non-stress accent*. Walter de Gruyter, vol. 7, 1986.

[2] D. B. Fry, "Duration and intensity as physical correlates of linguistic stress," *The Journal of the Acoustical Society of America*, vol. 27, no.4, pp.765-768, 1955.

[3] N. Campbell, and M. Beckman, "Stress, prominence, and spectral tilt," *Proceedings of ESCA Workshop on Intonation: Theory, Models and Applications*, pp. 67–70, 1997.

[4] P. Lieberman, "Some acoustic correlates of word stress in American English," *The Journal of the Acoustical Society of America*, vol. 32, no.4, pp. 451-454, 1960.

[5] A. M. Sluijter, and V. J. Van Heuven, "Spectral balance as an acoustic correlate of linguistic stress," *The Journal of the Acoustical society of America*, vol.100, no.4, pp. 2471-2485, 1996.

[6] H. Fujisaki, K. Hirose, and M. Sugito, "Comparison of acoustic features of word accent in English and Japanese," *Journal of the Acoustical Society of Japan (E)*, vol.7, no. 1, pp. 57-63, 1986.

[7] G. Kochanski, and C. Orphanidou, "What marks the beat of speech?," *The Journal of the Acoustical Society of America*, vol. 123, no. 5, pp. 2780-2790, 2008.

[8] B. Hayes, and A. Lahiri, "Bengali intonational phonology," *Natural Language & Linguistic Theory*, vol.9, no. 1, pp. 47-96, 1991.

[9] S.K. Chatterji, "Bengali Phonetics," *Bulletin of the School of Oriental and African Studies*, vol.2, pp.1-25, 1921.

[10] M. B. Emeneau, "India as a linguistic area," *Language*, pp.3-16, 1956.

[11] S.D. Khan, *Intonational Phonology and Focus Prosody in Bengali*. PhD dissertation, UCLA, 2008.

[12] J. (Ed.). Archibald, *Phonological acquisition and phonological theory*. Psychology Press, 2014.

[13] U.Weinreich, *Languages in contact: Findings and problems.* Walter de Gruyter, 1979.

[14] R. C. Major, *Foreign accent: The ontogeny and phylogeny of second language phonology*. Routledge, 2001.

[15] H. Wode, "The beginnings of non-school room L2 phonological acquisition," *IRAL-International Review of Applied Linguistics in Language Teaching*, vol. 16, no. 1-4, pp.109-126, 1978.

[16] D. B. Fry, "Experiments in the perception of stress," *Language and speech*, vol.1, no. 2, pp.126-152, 1958.

[17] T. Visceglia, C.Y. Tseng, M. Kondo, H. Meng, and Y. Sagisaka, "Phonetic aspects of content design in AESOP (Asian English Speech cOrpus Project)," in *Speech Database and Assessments,* 2009, *Oriental COCOSDA International Conference,* 2009, pp. 60-65.

[18] N. Amir, and O. Amir, "Novel measures for vowel reduction," in *Proceedings of the 16th International Congress of Phonetic Sciences*, 2007, pp. 849-852.

[19] M. Blomgren, M. Robb, and Y. Chen, "A note on vowel centralization in stuttering and nonstuttering individuals," *Journal of Speech, Language, and Hearing Research*, vol. 41, no.5, pp.1042-1051, 1998.

[20] M. Kul, "Towards a gradual scale of vowel reduction: a pilot study," *Poznan Studies in Contemporary Linguistics*, vol. 46, no.4, pp. 429-456, 2010.