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Homogeneity vs heterogeneity in Indian English: Investigating influences of L1 on f0 range

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Abstract

We present an exploratory analysis of several long-term distributional measures of f0 range in the speech of university-educated speakers of Indian English from four L1 backgrounds (Telugu, Tamil, Hindi and Bengali). The aim of this study is to investigate the degree of homogeneity in Indian English prosody and any similarities between the speakers' productions in English and their L1. Following recent studies, we examine three aspects of f0 range: pitch level (relative height of habitual f0), pitch span and pitch dynamism. Overall, across varieties, pitch level measures reveal individual speaker differences and only weak L1 effects on max f0 and median f0. Some speakers show higher f0 in their L1 productions compared to their English productions. More robust patterns were found for pitch span and dynamism: for all measures (maximum-minimum f0, pitch dynamism quotient and standard deviation), significant differences were found between L1 and English (p<0.001) for Bengali and Telugu L1 speakers. The relative weakness of L1 effects would suggest a degree of homogeneity in Indian English, at least for the prosodic parameters investigated. Evidence of a shift in pitch span when talking in English, regardless of L1, further suggests a convergent speech variety.

Index Terms: fundamental frequency, pitch range, Indian English, pitch span

1. Introduction

A growing body of research investigating similarities and differences across varieties of English demonstrates that post-colonial varieties of English have developed their own prosodic and intonational features, often distinct from the varieties of British and American English [1-6]. An ongoing question raised in the current literature is how best to capture this prosodic variation and how to define its parameters. Fundamental frequency (f0) range is one of the parameters that is often overlooked, most likely due to the complexity of the phenomenon and the multitude of approaches to its analysis [7,8]. f0 is, however, fundamental to our understanding of prosodic structure in new English varieties, in terms of its phonological representation, its phonetic realisation, and its position in prosodic typology in general. Previous research has shown cross-language differences in the use of pitch [i.e. 7,9,10] on the basis of several dimensions: pitch level, relative height of habitual f0, pitch span, the spatial difference between high and low turning points, and pitch dynamism. The present study aims to apply these dimensions using several f0 measures to examine pitch range in Indian English (IndE) in order to investigate any differences in the use of pitch range between IndE and speakers' L1s, and to explore any influences of L1 on IndE.

'Indian English' is a term commonly applied to the variety(/ies) of English as used by speakers in India (and also by the Indian diaspora around the world). The vast majority of IndE speakers in India are native speakers of one or more indigenous Indian languages, and while some are exposed to English at home from a very early (pre-school) age, most are exposed from school (at varying stages). Despite the wide and generalised application of the term, the concept of IndE is somewhat hard to pin down, owing to a variety of factors, including vast linguistic diversity and complex multilingualism, factors themselves shaped by rapidly changing socio-economic conditions.

The influence of indigenous L1s for some features is strong [see 11,12,13] potentially leading to the identification of multiple varieties of IndE. However, systematic heterogeneity is not a given: firstly, any these substrate features may themselves be independently convergent (i.e. identifiable as 'areal features', in segmental phonology [14] and prosody [15]), and secondly, other unified target features may also emerge in the process of standardisation of IndE [16]. There is thus on-going debate in the literature over the status of IndE [17,18,19] and the question of whether we are dealing with essentially a single pan-Indian variety or multiple sub-varieties [16,17,3-6].

Limited work has been conducted on the intonation of IndE, especially the use of f0 range, with earlier work being mostly auditory and descriptive. [20] suggests narrower pitch range for speakers of IndE in comparison to BrE. Recent experimental studies present more complex results indicative of influences from specific L1s [6,4,21], with the added complexities that the extent of L1 influence may vary depending on the feature under investigation [16,6,4], and potential differences based on the language family of the speakers' L1s (Indo-Aryan vs Dravidian). [4,6,22], for example, report a wider pitch span for speakers of IndE whose L1 is an Indo-Aryan language compared to speakers whose L1 is a Dravidian language. These findings, however, are based on a limited number of speakers, often restricted to one or two L1 backgrounds, and do not specifically investigate the dimension of f0 range.

To date, only [23] has examined f0 pitch range in IndE, finding higher pitch level in IndE compared to British Inglish (BrE), but also reporting differences between two speech styles (smaller pitch range in IndE in read speech and wider in spontaneous speech). [23]'s findings also suggest small but not significant differences on the basis of L1, indicative of homogeneity rather than heterogeneity in IndE on the basis of the parameters investigated. There is a dearth of studies in this area of IndE prosody, with existing studies typically comparing

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IndE with BrE or American (AmE), and little comparison, if any, carried out with L1s. More generally, there has been limited fine-grained acoustic research on the intonation of South Asian languages, especially on f0 range. Further research into pitch range measures in IndE is thus timely.

Factors potentially influencing f0 measures are numerous and complex, and many are rooted in differences in the prosodic structure between substrate languages and English (e.g. British or American varieties). Compared to the documented South Asian languages [24,25,26], BrE and AmE have a) a larger pitch accent inventory and as a result greater "variability" in pitch movements (different shapes); and b) variability in accentuation pattern, related to information structure and meaning. Research on Hindi, Bengali, and Tamil [27-30] documents certain salient features shared across South Asian languages, e.g. the accentuation of every prosodic word, and a repetitive rising contour throughout an utterance that is not affected by information structure and focus. In addition, every prosodic word forms a lower level prosodic unit, with peaks corresponding to phrase accents, unlike in English where peaks on accented words are modelled as pitch accents.

Identifying the prosodic structures of IndE presents challenges due to the variability in its usage and status across speakers, and the associated variability in its relationship with, and thus influence from, L1s. Long-term distributional measures in f0 can provide a pre-linguistic in-road to a comparative analysis of IndE and L1s. The wider framework of our research will be to look at linguistic measures, given these are found to be more robust when examining cross-linguistic differences in f0 range. Following [7], subsequent research will examine several landmarks to investigate pitch level (prominent initial and non-initial peaks, initial and non-initial prominent peaks combined, non-prominent initial peaks and phrase-final lows) and a combination of various measures based on these landmarks to investigate pitch span. This study seeks to provide a preliminary analysis of a subset of f0 measures (pitch level, span, dynamism) as a basis for these further analyses.

2. Method

2.1. Speakers

Six female and two male speakers of IndE were recorded at the University of Hyderabad, India. All speakers were enrolled in a university degree at the time of data collection, had started learning English at the age of 4-7 years, identified as bi- or multilingual, and were aged 22 to 30. The participants represented four L1 backgrounds (2 speakers each): Tamil and Telugu (Dravidian languages), and Hindi and Bengali (Indo-Aryan languages) (Fig 1). The two male participants were both speakers of Tamil. Participants sharing an L1 spoke the same dialect, with the exception of Bengali. One L1 Bengali speaker (BEN_F_1) grew up in Guwahati, Assam, and acquired an Eastern variety of Bengali (she also lived in various places in India), while the other came from West Bengal (Uttarpara).

2.2. Materials and processing

The speakers were asked to read "The North Wind and the Sun" passage, in English and in their L1, three times in a 'neutral' voice (as if telling a story). As this is an exploratory study refining methods and directions for larger-scale research, read speech was chosen for establishing a relatively formal baseline. Though small differences in mean f0 between read and spontaneous speech have been reported, read speech has been found to be an overall reliable medium for studies of f0 patterns [31]. Recent research has, however, shown some differences between the two speech styles for speakers of IndE [23]. We consider the implications of these findings further, in relation to both IndE and to Indian L1s, in our discussion.

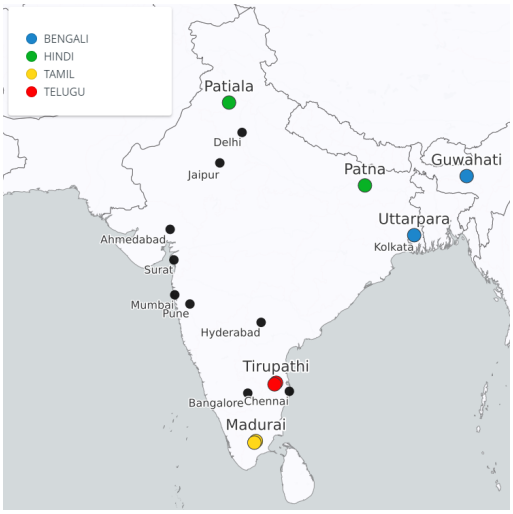

Figure 1: *Map of India showing participants' places of birth, presented by L1 (Bengali – blue, Hindi – green, Tamil – yellow, Telugu – red).*

Speakers were recorded in a quiet room using a Zoom H4nSP audio recorder with a lapel microphone, at a sampling rate of 44.1 kHz and 16-bit depth. For each speaker, the iteration deemed to have the most natural reading was selected for further analysis and converted into a mono .wav file. Using broad phonetic transcription, the selected recordings were automatically segmented via the web interface of the Munich Automatic Segmentation System (WebMAUS) using the language-independent model [32]. The segmentation was then manually corrected where necessary in Praat [33], and further annotations were added across different tiers. These included annotations of the intonational phrases (IPs), the highest level prosodic constituent in each file. The number of IPs per recording is shown in Table 1. Consistent with the Autosegmental-Metrical approach to intonation modelling [24,25], IP boundaries were identified on the basis of several criteria, including the presence of a pause or other discontinuity, pitch range reset (initially) and syllable lengthening (finally).

Table 1: *Number of IPs for each speaker when producing the narrative in their L1 compared to IndE.*

Speaker	L1	# L1 IPs	# IndE IPs
BEN_F_1	Bengali	21	21
BEN_F_2	Bengali	17	20
HIN_F_1	Hindi	17	21
HIN_F_2	Hindi	20	22
TAM_M_1	Tamil	29	22
TAM_M_2	Tamil	28	24
TEL_F_1	Telugu	29	24
TEL_F_1	Telugu	29	25

Using a modified Praat script [34], several f0 measures relating to pitch level, pitch span and dynamism were extracted for each IP. These were expressed in Hertz as well as in semitones (ST) for some of the measures (e.g. [35], [36]), converted using a 100Hz reference point (12*log2(f0/100)).

2.3. Measurements and analysis

For pitch level we analysed the measures of mean, median, minimum and maximum f0, following the approach developed by [8] and applied in [7]. For the analysis of pitch span we used a subset of the measures listed in [7] as the starting point of investigation on pitch range in IndE. These include standard deviation (SD) and maximum minus minimum f0 (max-min f0). We also added a measure of pitch dynamism quotient (*pdq*), which was calculated by dividing the SD in f0 by its mean in Hz [23,37]. The latter allows us to compare findings with those of [23]. Consistent with previous research [see 7], analyses of pitch level measures were performed in Hz. An attempt was made to account for f0 differences across adult male and female voices by applying a normalization technique used in [23]. However, due to the particularly high pitch register for one of the Tamil speakers (in both L1 and IndE), this approach was not implemented. Pitch span measures were examined in ST, a common and more suitable approach to examining the frequency differences and variability.

Analyses were undertaken in R [38], and statistical tests were conducted using the lmer() function in the lme4 package [39]. A series of linear mixed-effects models (LMM) were fitted with recorded language (English vs L1) and L1 as fixed factors, and speaker as a random factor for each of the measures listed above. This approach allowed us to avoid multicollinearity of the variables under investigation. Gender was not included as a random factor due to individual differences between the two male speakers and the aforementioned relatively high pitch level for speaker TAM_M_2. Likelihood ratio tests between null and full models predicting the effects of recorded language and L1 were performed. In addition, using the step function in the lmerTest package [40], backwards removal of non-significant fixed factors was completed. Except for minimum f0, where a step function test suggested eliminating the fixed factor of L1, modelling for all measures retained the factors of L1 and recorded language.

3. Results

3.1. Pitch level

3.1.1. Minimum and maximum f0

The results for minimum f0 indicate no differences across the speakers based on their L1 background and suggest a weak significant effect of recorded language (t=2.43, p=0.02). A closer examination reveals no consistent pattern: some of the speakers use higher minimum f0 in their L1 productions, while for others the higher minimum f0 is in IndE. In addition, the analysis shows a large degree of inter- and intra-speaker variation, especially for Hindi speakers (both in L1 and IndE) and Telugu speakers (in L1).

Despite a significant effect of L1 in the model, the measure of maximum f0 is more reflective of speakers' individual pitch levels and the differences between male and female use of pitch register (see Fig 2), rather than being indicative of any patterning based on L1 background. The two male Tamil speakers have lower maximum f0 in L1 and IndE compared to the (female) speakers of Bengali and Hindi, as we might expect. For any cross-language systematicity in absolute measures, a much larger corpus and pool of speakers is needed. Looking at the difference in maximum f0 between the speakers' L1 and IndE, however, the LMM analysis confirms a highly significant effect of recorded language (t=4.09, p<0.001). For a number of speakers, a pattern emerges showing higher maximum f0 for L1 productions as compared to IndE. Further examination of the interaction between recorded language and L1 confirms that speakers with Bengali and Hindi as their L1 adjust and lower their pitch register when speaking in IndE (L1 Bengali speakers: t=5.68, p<0.001; L1 Hindi speakers: t=2.38, p<0.02). A similar pattern is seen for Telugu, but without statistical significance, whereas for Tamil only one of the speakers employed a higher max f0 in his L1. For speaker TAM_M_2, recorded language has the opposite effect, with max f0 higher in his IndE production. This pattern is maintained for other measures. The speaker could be lowering his pitch register and decreasing his pitch span for IndE, given his unusually high pitch range in his L1.

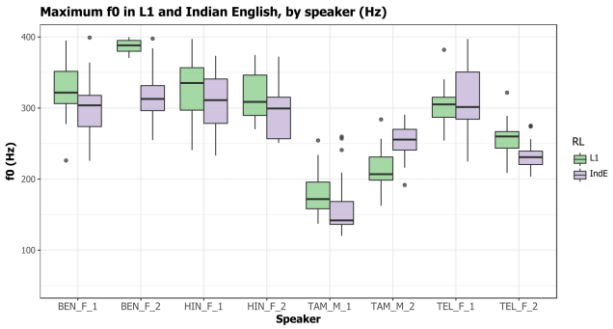

Figure 2: *Maximum f0 (in Hz) by recorded language (L1 – green, IndE – purple) and speaker.*

3.1.2. Mean and median f0

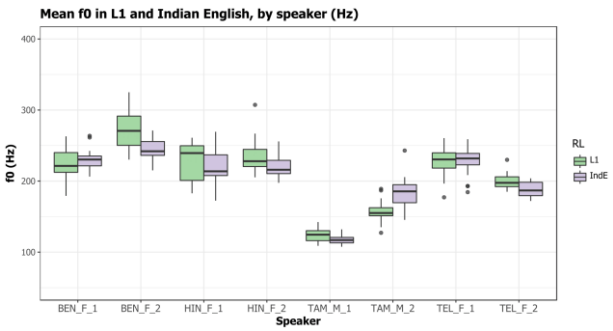

Figure 3: *Mean f0 (in Hz) by recorded language (L1 – green, IndE – purple) and speaker.*

Similar to maximum f0, for the measures of mean f0 (Fig 3) and median f0, differences across the speakers could be attributed to individual differences and, to a degree, differences between the f0 range in males vs. females. Female speakers of L1 Hindi and L1 Bengali have a higher f0 mean and median in both IndE and L1 in comparison to the two male speakers of L1 Tamil. This pattern does not extend to L1 Telugu speakers simply because of the relatively lower pitch register for one of the female speakers. While the present dataset does not provide a conclusive set of results, it potentially suggests that looking at pitch level measures may not be sufficient for examining cross-language and cross-dialectal differences in f0 range. Further, applying normalisation of f0 values to account for the differences in male and female voices may mask patterns in

varieties and possibly speech style.

Looking at the effect of recorded language on mean and median f0, and the interaction between recorded language and L1, a post-hoc test confirms significant differences between IndE and L1 productions for L1 Tamil speakers (mean f0: t=3.21, p=0.002; median f0: t=3.49, p<0.001) and L1 Hindi speakers (mean f0: t=2.71, p=0.007; median f0: t=2.81, p<0.01). Curiously, only one Bengali speaker (BEN_F_2) has higher mean and median f0 in her L1 productions, in contrast to the maximum f0 results.

3.2. Pitch span and dynamism

3.2.1. Max-min f0 and standard deviation

Looking at the differences between maximum and minimum f0 (Fig 4) and SD (Fig 5), the results present a more comprehensive picture about the use of pitch range in IndE. The model found no effect of L1. As shown in the figures below, there is some variation across the speakers but limited evidence for L1-based differences in IndE and across L1 productions. The presence of a weak effect of L1 between L1 Tamil and L1 Hindi (t=2.81, p=0.04) could be due to one of the Hindi speakers having a wider span. Interestingly, the variability in f0 pitch modulation does not reflect any differences between male and female voice on the basis of these measures. The investigation of pitch span on a larger corpus could potentially be more sensitive to any differences across L1s and for gender, if and where these exist.

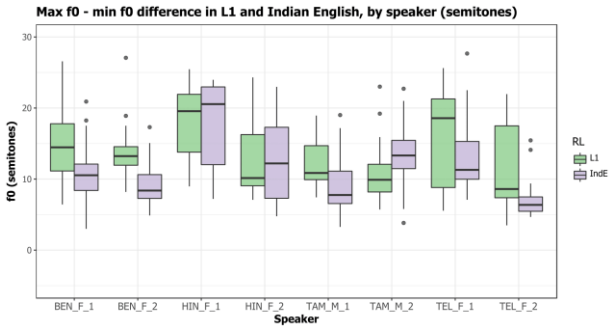

Figure 4: *Pitch range (max-min f0 in ST) by recorded language (L1 – green, IndE – purple) and speaker.*

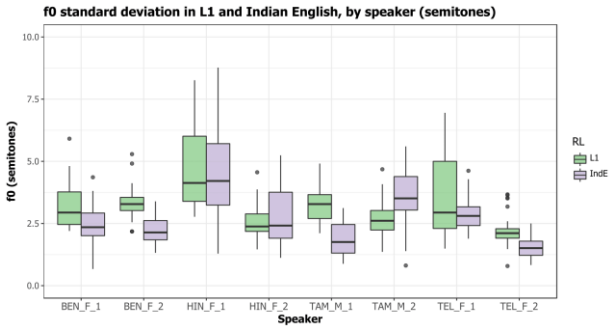

Figure 5: *Standard deviation (in ST) by recorded language (L1 – green, IndE – purple) and speaker.*

In addition, the results reveal a cross-type pattern similar to that reported for three pitch level measures, in that a number of speakers reduce their pitch span when speaking IndE. Recorded language has a significant effect on measures max-min f0 (t=-4.86, p=0.001) and SD (t=-5.07, p<0.001). Post-hoc tests further confirm differences across L1 and IndE productions for the speakers of Bengali (max-min f0: t=5.98, p<0.001; SD: t=5.79, p<0.001) and Telugu (max-min f0: t=2.84, p=0.005; SD: t=3.1, p<0.01), but not Hindi, unlike the measure of maximum f0.

3.2.2. Pitch dynamism quotient

We find a similar pattern of behaviour with *pdq* as for the two pitch span measures, namely that there is no effect of L1, but there is a significant effect of recorded language (IndE vs L1 – wider span for L1): t=-4.62, p<0.001. There is also a significant interaction between L1 and recorded language for Bengali (t=4.29, p<0.001) and Telugu speakers (t=2.95, p<0.01). As can be seen in Figure 6, there are large differences in *pdq* between L1 and IndE for L1 Bengali and L1 Telugu speakers, and for one L1 Tamil speaker, with *pdq* considerably higher in L1 productions.

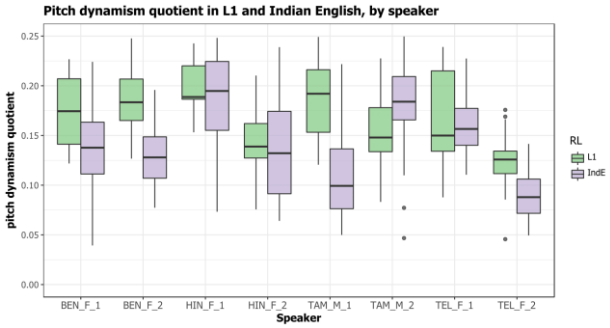

Figure 6: *Pitch range (pdq) by recorded language (L1 – green, IndE – purple) and speaker.*

4. Discussion

The findings of this exploratory study suggest that any systematic differences that might exist across L1s, for the f0 measures investigated here, are subtle and require a much larger corpus in order to be robustly detected. Spontaneous speech may also reveal larger or more systematic cross-L1 differences. However, it may also be the case that Indian L1s display a sufficient set of prosodic areal features to ensure relative homogeneity in these specific f0 measures. In contrast, the relatively robust findings for systematic differences between L1 and IndE, even for such a small dataset, suggest a tangible shift in prosodic behaviour when speakers switch from their L1 to IndE. The implications for speech behaviour at the L1-L2 interface and multilingualism more generally, and for the status and relative homogeneity of IndE as a distinct variety of English, are plentiful. Our next step will be to investigate to what extent this shift is generalisable to a larger pool of speakers, and also to different speech settings (comparing more or less formal speech styles). We shall also seek to identify whether such a shift is an artefact of distinct prosodic structures in IndE, compared with L1s, or whether this is a more holistic characteristic of IndE.

5. Acknowledgements

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6. References

[1] C. Gussenhoven, "On the intonation of tonal varieties of English," in *The Oxford Handbook of World Englishes*, M. Filpulla, J. Klemola and D. Sharma, Eds. Oxford: Oxford University Press, 2014, pp. 569-598.

[2] U. Gut, "Nigerian English prosody," *English World-Wide*, vol. 26 (2), pp. 153-177, 2005.

[3] R. Fuchs, *Speech rhythm in varieties of English: Evidence from Educated Indian English and British English*. Singapore: Springer, 2016.

[4] O. Maxwell, *The Intonational Phonology of Indian English: An Autosegmental-Metrical Analysis Based on Bengali and Kannada English*. PhD thesis, University of Melbourne, Melbourne, Australia, 2014.

[5] O. Maxwell and J. Fletcher, "Tonal alignment of focal pitch accents in two varieties of Indian English," in *Proceedings of the 15th Australasian International Speech Science and Technology Conference, SST2014*, J. Hay and E. Parnell, Eds. Christchurch: Australasian Speech Science and Technology Association, 2014, pp. 59-62.

[6] C. Wiltshire and J. Harnsberger, "The influence of Gujarati and Tamil L1s on Indian English: A preliminary study," *World Englishes*, vol. 25(1), pp. 91-104, 2006.

[7] I. Mennen, F. Schaeffler, and G. Docherty, "Cross-language differences in fundamental frequency range: A comparison of English and German," *Journal of the Acoustical Society of America*, vol. 131(3), pp. 2249-2260, 2012.

[8] D. Patterson, "A linguistic approach to pitch range modelling," Ph.D. thesis, University of Edinburgh, Edinburgh, UK, 2000.

[9] W. Majevski, H. Hollien, and J. Zalewski, "Speaking fundamental frequency in Polish adult males," *Phonetica*, vol. 25(2), pp. 119-125, 1972.

[10] U. Gut, *Non-native Speech: A Corpus-based Analysis of Phonological and Phonetic Properties of L2 English and German*. Frankfurt: Peter Lang, 2009.

[11] R. K. Bansal, "A phonetic analysis of English spoken by a group of well-educated speakers from Uttar-Pradesh," *CIEFL Bulletin (Hyderabad)*, vol. 8, pp. 1-11, 1970.

[12] T. Balasubramanian, "The vowels of Tamil and English: A study in contrast," *CIEFL Bulletin (Hyderabad)*, vol. 9, pp. 27-34, 1972.

[13] Z. Thundy, "The origins of Indian English," *CIEFL Bulletin (Hyderabad)*, vol.12, pp.29-40, 1976.

[14] C. Masica, *Defining a Linguistic Area: South Asia*. New Delhi: Chronicle Books, 2005.

[15] S. D. Khan, "The intonation of South Asian languages," *Proceedings of FASAL-6*, pp. 23-36, 2016.

[16] H. Sirsa and M.A. Redford, "The effects of native language on Indian English sounds and timing patterns," *Journal of Phonetics*, vol. 41(6), pp. 393-406, 2013.

[17] P. Sailaja, "Indian English: Features and sociolinguistic aspects," *Language and Linguistics Compass*, vol. 6(6), pp. 359–370, 2012.

[18] J. Mukherjee, "Steady states in the evolution of new Englishes: Present-day Indian English as an equilibrium," *Journal of English Linguistics*, vol. 35(2), pp. 157-187, 2007.

[19] E. Schneider, *Postcolonial English: Varieties Around the World*. Cambridge: Cambridge University Press, 2007.

[20] P. Nihalani, R.K. Tongue, P. Hosali, and J. Crowther, *Indian and British English: A Handbook of Usage and Pronunciation* (2nd ed.). Oxford: Oxford University Press, 2004.

[21] V. Puri, *Intonation in Indian English and Hindi Late and Simultaneous Bilinguals*. PhD thesis, University of Illinois, Illinois, United States, 2013.

[22] R. Moon, *A Comparison of the Acoustic Correlates of Focus in Indian English and American English*. Master's thesis, University of Florida, Florida, United States, 2002.

[23] R. Fuchs, "Pitch range, dynamism and level in postcolonial varieties of English: A comparison of Educated Indian English and British English,", forthcoming.

[24] D. R. Ladd, *Intonational Phonology*. Cambridge: Cambridge University Press, 2008.

[25] M.E. Beckman and Elam, G.A, *Guidelines for ToBI Labelling* (version 3). Ohio: Ohio State University Research Foundation, 1997.

[26] S.-A. Jun (Ed.), *Prosodic Typology II: The Phonology of Intonation and Phrasing*. Oxford: Oxford University Press, 2014.

[27] E. Keane, "The intonational phonology of Tamil," in *Prosodic Typology II: The Phonology of Intonation and Phrasing*, S.-A. Jun, Ed. Oxford: Oxford University Press, 2014, pp. 118-153.

[28] B. Hayes and A. Lahiri, "Bengali intonational phonology," *Natural Language and Linguistic Theory*, vol. 9(1), pp. 47-96. 1991.

[29] U. Patil, G. Kentner, A. Gollard, F. Kuhler, C. Féry, and S. Vasishth, "Focus, word order, and intonation in Hindi," *Journal of South Asian Linguistics*, vol. 1(1), pp. 1-21, 2008.

[30] S. D. Khan, "The intonational phonology of Bangladeshi Standard Bengali," in *Prosodic Typology II: The Phonology of Intonation and Phrasing*, S.-A. Jun, Ed. Oxford: Oxford University Press, 2014, pp. 81-117.

[31] R.J. Baken and R. F. Orlikoff, *Clinical Measurement of Speech and Voice* (2nd ed.). San Diego: Singular Thomson Learning, 2000.

[32] T. Kisler, U. Reichel, and F. Schiel, "Multilingual processing of speech via web services," *Computer Speech and Language*, vol. 45, pp. 326-347, 2017.

[33] P. Boersma and D. Weenink, "Praat: Doing phonetics by computer" [Computer program, version 6.0.37]. Available: www.praat.org, 2018.

[34] Y. Nijs, "PraatPitch" [Praat script]. Available: github.com/YoeriNijs/PraatPitch, 2016.

[35] F. Nolan, "Intonational equivalence: An experimental evaluation of pitch scales," *Proceedings of the 15th International Congress of Phonetic Sciences*, pp. 771-774, 2003.

[36] F. Kügler, "A model for the quantification of pitch accent realization," in *Variation and Gradience in Phonetics and Phonology*, F. Kügler, C. Féry, and R. Van den Vijver, Eds. Berlin: Mouton, 2009, pp. 405-424.

[37] R. Hincks, "Processing the prosody of oral presentations," *Proceedings of InSTIL/ICALL 2004 - NLP and Speech Technologies in Advanced Language Learning Systems*, pp.63-69, 2004.

[38] R Core Team, "R: A language and environment for statistical computing" [Computer program, version 3.2.2]. Austria: The R Foundation for Statistical Computing. Available: www.r-project.org, 2015.

[39] D. Bates, M. Maechler, B. Bolker, and S. Walker, "Fitting Linear Mixed-Effects Models using lme4," *Journal of Statistical Software*, vol. 67(1), pp. 1-48, 2015.

[40] A. Kuznetsova, P. B. Brockhoff, and R. H. B. Christensen, "lmerTest package: Tests in Linear Mixed Effects Models," *Journal of Statistical Software*, vol. 82(13), pp. 1-26, 2017.