Original Article

Comparing Fundamental Frequency within and Across Speakers of Hindi and English

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Abstract

Introduction: The objective of this study was to compare fundamental frequency (F_0) during vowel phonation, reading, and monolog in Indian Hindi speakers as compared to native English speakers. **Methods:** Thirty normal, age-matched native English and 30 Indian Hindi speakers participated in the study. Participants' F_0 values were extracted from samples obtained during sustained/a/, reading, and monolog. Analyses centered on F_0 differences during (a) sustained/a/, comparing native English and Hindi speakers; (b) reading and monolog production, comparing native English and Hindi speakers speaking English and Hindi, respectively; (c) reading and monologs, comparing native English versus Hindi speakers speaking English; and (d) Hindi participants speaking English versus the same participants speaking Hindi. **Results:** Analyses did not reveal significant differences between F_0 during sustained/a/for native English and Hindi speakers. All other comparisons, which involved reading and monolog, revealed significantly higher F_0 in Hindi speakers. Relationships between language learning variables and mean F_0 were statistically insignificant. **Conclusions:** The finding of equivalent F_0 for sustained vowel phonation across groups, in comparison to between- and within-group differences for reading and monolog tasks, suggests that F_0 differences that were found were largely linguistically determined. Proposals are provided for evaluating additional anatomical and cultural factors determining F_0.

Keywords: English, fundamental frequency, Hindi, multilinguistic

Introduction

A speaker's geographic background is usually associated with a unique language and perhaps a dialect within a language. Some reports have indicated that vocal characteristics may also vary with geography which may be relevant in the clinical evaluation of an individual's voice.[1] In fact, voice disorders have been defined as conditions in which one or more aspects of voice, such as loudness, pitch, quality, or resonance, are outside of the normal range for the age, gender, or geographic background of the speaker.[2]

The focus of this study was to examine differences in fundamental frequency (F_0) values across Indian Hindi speakers and native English speakers. F_0 reflects the rate at which the vocal folds vibrate during phonation, which may vary across languages, like that of Jordanian Arabic-speaking children who spoke at higher F_0 values during sustained vowel/a/than their Western, English-speaking counterparts.[3]

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It is speculated whether F_0 differences occur due to physical or linguistic and cultural factors or both. Tom[4] pointed to anatomical and physiological differences as a likely basis for F_0 variations across some populations. In contrast, Shriberg and Kent[5] suggested that linguistic features such as prosody may influence F_0. Recent research has shown that F_0 may vary not only across languages in native speakers but also may shift in the same individual speaking different languages. One study of highly proficient German-English speakers revealed significantly higher mean F_0 when participants spoke in English compared to speaking in German.[6] Conceptually, similar findings reported that differences in F_0 can also occur across dialects within a language.[7]

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Clearly, F_0 shifts in these studies are indicative of linguistic or cultural as opposed to physical causal factors. However, physical factors such as laryngeal size cannot be ruled out. In any event, adequate clinical assessment of voice requires that the speaker's linguistic background is considered when comparing a patient's F_0 value to norms.[8]

Unfortunately, norms for fundamental frequency are lacking for many populations, especially in multilingual populations like in India.[9] Few normative studies have been published on F_0 or other vocal parameters in Hindi speakers; therefore, normative data from studies of Western countries are generally used clinically, perhaps ill-advisedly. On the surface, some findings indicate that the use of Western normative data for F_0 in Indian Hindi speakers may be reasonable, including studies that failed to detect differences in F_0 values for sustained vowels for Hindi compared to American English speakers.[10] However, F_0 may vary significantly with actual language production as opposed to simple, sustained phonation.[6] If running speech is used to extract habitual F_0, there would be value in knowing whether F_0 values differ across native speakers of different languages, including speakers producing their native language and postnatively acquired languages. Findings could provide information in the ultimate generation of F_0 norms for international speakers, particularly Hindi speakers, including those living outside of India with over one million alone in the US.[11] Findings could also be useful for theoretical speculation about the role of physical versus linguistic and cultural factors in F_0 and other vocal variations across populations.

Comparison of F_0 during isolated vowel phonation was completed across Hindi/English speakers and monolingual American English speakers to extend research of previous studies.[10] To extend the understanding of the voice of the Hindi/English bilingual speaker, comparison of reading and monolog tasks was also undertaken for the two groups.[12] Within-group comparisons of F_0 in the bilingual group were completed to control for physical difference of the vocal mechanism inherent to across-group comparisons, allowing examination of the influence of the two languages on mean F_0. Finally, variables used to explore relationships for pronunciation/accent in second-language learners were applied to evaluate relationships between these variables and F_0, including length of time in the US, use of English in daily living, and confidence in speaking English. The addition of running speech tasks, within- and cross-group comparisons, and the exploration of language learner variables should contribute to identifying potential variations in F_0 across the two languages.

Methods

Participants

This study was approved by the Institutional Review Board at the University of Central Missouri, Warrensburg, Missouri. All participants signed an informed consent before participation. Thirty native Indian Hindi male speakers (age: 20–25 years) and 30 age-matched native English male speakers, all living in the US, were recruited for participation. A "snowball" recruitment method was used to attract subjects. On the day of participation, all speakers exhibited normal voice, speech, and language in both Hindi (Indian speakers) and English (all speakers), as informally judged by a speech-language pathologist proficient in both languages. Participants reported no history of articulation, voice, language, or hearing difficulties. Participants reported good general physical health and denied any history of medical conditions that might adversely influence voice. Participants were nonsmokers and had no previous formal voice training. Each participant passed a bilateral pure-tone hearing screening.[13]

All native Indian Hindi speakers considered English their second language and reported learning both spoken and written English as part of their formal education in India though formal education varied from person to person. All participants were naive to the purposes of the study. Table 1 provides information on participants' languages spoken and time in the US.

Equipment and data acquisition

Voice samples were recorded in a single-walled, sound-treated chamber (Acoustic System Model RE-143MC) with an average ambient noise of 40 dB. The KayPENTAX Computerized Speech Lab (CSL) Model 4500, (KayPENTAX**,** Lincoln Park, NJ) was used to collect voice samples. A head-worn cardioid condenser microphone (CROWN CM-311A) was positioned 45° off-axis from the corner of the subject's mouth on the right side of the body.

Procedures

Five voice samples were collected from native Indian Hindi-speaking participants; three samples were collected from native English-speaking participants.[14] Subjects were instructed to speak at a comfortable pitch and loudness for all tasks. All subjects (i) produced one sustained/a/for 5 s, (ii) read the complete version of the rainbow passage out loud, in English,[14] and (iii) produced a 1–2-min monolog speech sample of subjects' choice about one of four topics: a summer vacation, a favorite movie, a place visited recently, or any aspect of their native country they wished to discuss in English. In addition, native Indian Hindi speakers were asked (iv) to read a Hindi passage comparable in length and difficulty to the English rainbow passage, prepared by a proficient speaker of Hindi and English, and (v) to produce a 1–2-min monolog in Hindi on one of the four topics noted above. The order of task presentation was randomized across speakers.

Data analysis

The real-time pitch program was adopted for analysis of F_0 for each sample. Entire sample of sustained/a/was analyzed. In analysis of running speech samples, the midpoint of the sample was identified, and a segment 30 s before and after the midpoint was extracted to acquire a 60-s sample.

Statistical analysis

The *t*-statistic was adopted to statistically analyze both between-group comparisons and within-group comparisons for the Hindi speakers (alpha = 0.05). A Bonferroni adjust $P = 0.007$ (0.05/7) was applied for the seven between- and within-group comparisons for the mean F_0. Relationships among dependent variables and descriptive variables associated with the Hindi-speaking group (i.e., number of years living in the USA, confidence in speaking English, and percent of time speaking English in Hindi before coming to the USA) were evaluated visually and through correlation analysis (Pearson product moment correlation coefficient). An adjusted $P = 0.006$ (0.05/9) was adopted for the correlation analysis.

Results

Mean F_0 findings

An independent-samples *t*-test compared F_0 between sustained/a/phonation in Hindi speakers and native English speakers. No evidence was found suggesting F_0 differences during sustained phonation across groups. Results are shown in Table 2.

Two independent-samples *t*-tests were conducted to compare average F_0 during running speech across the same two speaker groups, when participants spoke in their native language. F_0 was compared between Hindi speakers and English speakers reading in their native language. F_0 was also compared between Hindi speakers and English speakers producing a monolog in their native language. Indian Hindi speakers' F_0 during running speech in Hindi was higher compared to native English speakers' running speech in English for both tasks.

Similarly, two independent-samples *t*-tests were conducted to compare F_0 during running speech across native Indian Hindi and native English speakers, when both groups spoke in English. The first *t*-test compared F_0 between Indian Hindi speakers and native English speakers reading the same English passage. A second *t*-test compared F_0 between Indian Hindi speakers and native English speakers producing the same monolog in English. For both tasks, Hindi speakers' F_0 in English was higher than native English speakers' F_0.

Two paired-samples *t*-tests compared F_0 during running speech within native Indian Hindi speakers, when speaking in Hindi versus English. The first test compared F_0 for Hindi speakers reading in Hindi versus English. A second *t*-test compared F_0 for Hindi speakers producing monologs in English versus Hindi. F_0 in Hindi was significantly higher than F_0 in English [Table 3].

Table 1: Hindi participant's languages spoken

Languages spoken (# of participants)	Most comfortable language (# of participants)	Duration of stay in the US: <6 months	Duration of stay in the US: 6 months-1 year	Duration of stay in the US: 1+ year
Hindi, English, Malayalam, Marathi (2)	Hindi (2)			2
English, Hindi, Telugu, Tamil (1)	English (1)		1	
Telugu, English, Hindi (10)	Telugu (9); English (1)	1	8	1
English, Marathi, Hindi, Gujarathi, Urdu (1)	English (1)		1	
English, Hindi, Marathi, Gujarathi (2)	English (1); Hindi (1)		2	
Marathi, English, Hindi (8)	Marathi (5); English (1); Hindi (1)	5	1	2
Urdu, English, Punjabi, Hindi (2)	Urdu (1); English (1)			2
Hindi, English (1)	Hindi (1)			1
English, Hindi, Arabic (1)	English (1)			1
Bengali, English, Hindi, Urdu (1)	Bengali (1)			1

Most comfortable language and duration of stay in the US out of 29 participants (ages 20-25)

Table 2: F_0 Indian Hindi speakers versus native English speakers

Task	Indian Hindi speakers (Hz)	Native English speakers (Hz)	*P*	Semitone differences
Sustained/a/	Mean=130.70 SD=22.27	Mean=124.29 SD=17.41	0.219	0.87
Reading Hindi passage by Indian Hindi speakers versus reading English by native English speakers	Mean=143.50 SD=19.60	Mean=113.89 SD=13.29	<0.001	4.00
Monolog in Hindi by Indian Hindi speakers versus monolog in English by native English speakers	Mean=136.25 SD=18.76	Mean=109.97 SD=13.92	<0.001	3.70
Reading English passage by Indian Hindi speakers versus reading English by native English speakers	Mean=134.47 SD=19.70	Mean=113.89 SD=13.29	<0.001	2.87
Monolog in English by Indian Hindi speakers versus monolog in English by native English speakers	Mean=129.99 SD=19.84	Mean=109.97 SD=13.92	<0.001	2.89

SD: Standard deviation

Running speech tasks and language learning variables

Table 4 describes the relationships across three language learning variables and the mean F_0 for the three speaking tasks completed by Hindi/English speakers. No significant relationships were noted.

Reliability

Intra-measurement reliability estimates evaluated consistency of F_0 values. Six randomly selected participants from each group were selected to measure F_0 a second time for all tasks, for a total of 48 speech samples measured. The Pearson correlation coefficient (*r*) obtained between the first and second frequency measurements made by the investigator was 0.99, and mean absolute intra-measurement error was 5.42 Hz. The correlation was significant at 0.01 levels (two-tailed). High intra-measurement correlations and small absolute error indicate that F_0 values measured by the primary investigator were consistent and reliable. Inter-rater reliability of measurement was not assessed.

Data from 12 subjects were randomly selected for retesting to determine within-subject reliability of measures. These participants completed the experimental protocol a second time the next day at the exact same time of day. Samples were measured using the same measurement procedures as previously noted. F_0 values for the first data acquisition were compared to the second acquisition. The Pearson *r* correlation coefficient obtained between the first and second frequency measurements made by the investigator was 0.99, and mean absolute intra-measurement error was 10.88 Hz. This correlation was significant at 0.01 levels (two-tailed). High within-subject correlations and small absolute error indicate that frequency values produced by the participants were consistent and reliable.

Discussion

F_0 did not differ across native Indian Hindi versus native English speakers for sustained vowel production. However, consistent differences were detected across speakers in all running speech tasks. For running speech tasks, F_0 was consistently higher for Hindi speakers compared to native English speakers, whether they spoke in Hindi or English [Table 2]. Overall, Hindi speakers' F_0s remained roughly three semitones higher than F_0s for native English speakers, which may be perceptually notable and influence psychological responses of listeners.[15] This cross-language difference existed even when Indian Hindi speakers spoke in Hindi compared to their own English at about one semitone [Table 3]. Finally, preliminary exploration of relationships between language learning variables and mean F_0 for both sustained vowel and English running speech conditions for Indian Hindi speakers was not significant.

Intrinsic F_0 for the sustained/a/was virtually identical for Indian Hindi speakers and Anglo-European English American speakers, supporting previous findings of Andrianopoulos *et al*.[10] Both Hindi and English contain an/a/in phonological inventory of each language.[16] The/a/in Hindi is produced with a slightly advanced tongue position compared to English. Tongue height, however, is similar to English, a factor influencing intrinsic F_0 for vowels in words.[17] It appears that similar physiological mechanisms involved in alternating elasticity, tension, and mass of the vocal folds to alter F_0 are present in the vowel production of the two speaking groups. Alternate findings exist, however, for tone languages where the F_0 tends to be higher.[10,18] Altenberg and Ferrand[8] suggest not using sustained vowels when measuring F_0 for clinical normative data of bilingual speakers unless the clinician can document the language mode of the vowel being phonated.

Significant across-language differences in the mean F_0 existed for the connected speech tasks but not for the sustained vowel task, evident in both within- and between-group comparisons. Speaking in English or Hindi, Indian Hindi speakers exhibited a higher F_0 compared to the speech of Anglo-European males. Across-language differences exist between Hindi and English, which are further supported by similar F_0 for sustained vowel

Table 3: F_0 for Indian Hindi speakers in Hindi versus English

Task	Indian Hindi speakers in Hindi (Hz)	Indian Hindi speakers in English (Hz)	*P*	Semitone differences
Reading in Hindi versus English by Indian Hindi speakers	Mean=143.50 SD=19.60	Mean=135.77 SD=19.36	<0.000	0.95
Monolog in Hindi versus English by Indian Hindi speakers	M=136.25 SD=18.76	Mean=131.64 SD=19.98	<0.000	0.5

SD: Standard deviation

Table 4: Correlations between language learning variables and the mean F_0 in English for the three speaking tasks for the Hindi/English bilingual speakers*

Language learning variables	Mean F_0 for sustained/a/		Mean F_0 for reading passage in English		Mean F_0 for monolog in English	
Percentage of daily English usage while living in US	−0.202	*P*=0.285	−0.124	*P*=0.514	−0.077	*P*=0.685
# of years living in US	−0.209	*P*=0.268	−0.289	*P*=0.121	−0.273	*P*=0.145
Confidence in speaking English	−0.052	*P*=0.787	0.031	*P*=0.869	−0.092	*P*=0.63

*Using the Pearson product-moment correlations. Comparisons were made using English samples

comparisons. The sustained vowel task likely does not engage the suprasegmental or tonal aspects of the language and will not capture across-language differences.

By itself, higher F_0 in running speech among Hindi speakers may be the result of anatomical differences between Indian Hindi speakers and Anglo-European English speakers. When comparisons were made between Hindi and English running speech tasks produced solely by Hindi speakers, a significantly higher F_0 existed when the Hindi language was used. For this within-speaker comparison, anatomical differences cannot account for cross-language difference in mean F_0. The one semitone increase in F_0 while speaking in Hindi could be the result of differences in prosody between the two languages, not studied here.

In terms of cultural factors, habitual speaking intensity of Indian speakers is greater than their European peers due to their habitual need to speak in conditions where high levels of environmental noise exist.[19] A positive relationship exists between intensity of the voice and F_0. On average, a 2–4 Hz increase in F_0 occurs with every centimeter increase in subglottal pressure. Greater intensity and reduced vital capacity may be associated with increased adduction in the vocal folds to supplement maintenance of subglottal pressure. Data on speaking intensity and/or subglottal pressure should be obtained as a covariate when performing cross-group language comparisons to verify speaking intensity of Hindi speakers.

Finally, a lack of significant relationships between second-language acquisition and level of exposure, practice in daily life, and confidence with language may be the result of several factors. Most Indian Hindi speakers had experience speaking additional languages, and the influence of these languages on learning F_0 in American English is uncertain. Further, only eight Indian Hindi speakers indicated that Hindi was their most comfortable language. The more comfortable one is with a second language, the more likely native features of the language will be transmitted to a second language.[8]

The length of exposure for participants living in the US was shorter than many studies. A relationship may not exist between this variable and F_0, or the range of exposure time was not sufficient. Anecdotally, authors in the present study have interacted with Indian Hindi speakers who exhibited typical pitch values while speaking American English, but exposure was longer than in the present study.

The mean percent of time speaking English for Hindi/English speakers during an average day was 56% with a range of 6%–98%, suggesting that time speaking English during the day is not significantly related to F_0. Research on phonological acquisition of second-language learners suggests that the quality and/or type of speaking activities participated in may influence the acquisition of second-language features.

Finally, participants indicated how confident they were in speaking English using a 1–5 interval scale, 5 being most confident, to provide an indirect view of English language proficiency. Confidence in speaking English had little to do with the mean F_0. Over 70% of the speakers chose a value of 2, indicating limited confidence with the English language. Limited range of confidence level rating reduces the validity of the relationship.

Clinical implications

The findings provide that direction for tasks clinicians may use in attempts to obtain valid and reliable measures of F_0 in multilingual speakers. Arguably, F_0 in sustained phonation might reflect the physical status of the vocal folds, but if a clinician adopts sustained vowel F_0 as the sole metric of vocal fold vibration, he or she might miss findings indicated by running speech tasks and may not capture the difference in F_0 between languages. The type of task used to sample F_0 is central to understanding across-language differences.[18]

Beyond acoustic measures of F_0, most clinical evaluations include a perceptual component. With pitch, a clinician will make perceptual judgments generally based on internalized norms for age and gender. Clinicians may need to adjust their points of reference for pitch and possibly other perceptual parameters based on linguistic and cultural group. For the bilingual speaker, precautions may be required for acoustic and perceptual evaluations of voice.

Future directions

Results from the present study provide a promising direction for future research. One area for future research is the acquisition of normative F_0 data among speakers of various Indian languages and dialects. Moreover, data should be established for both monolingual and multilingual Indian speakers, which will improve the objective evaluation of F_0 for Indian languages. The influence of other acoustic (and perceptual) parameters in bilingual and multilingual populations beyond F_0 should be explored. Research should consider various proficiency levels of bilingual and multilingual speakers to estimate the influence of language proficiency on running speech F_0. The contributions of intensity of the voice on F_0 should be considered for the Indian Hindi-speaking population. Finally, future studies should also include female native Hindi speakers – who were not readily available in the subject pool – given reports of cross-task variability in F_0 for female speakers in general.[12,20]

Conclusions

The central aim of this study was to explore the influence of language among native Hindi speakers and native English speakers, using F_0. The results for sustained phonation on/a/ did not reveal significant differences across speaker groups. However, in running speech, F_0 for native Hindi speakers was consistently higher than for native English speakers, whether the Hindi speakers spoke in Hindi or English. Findings are most readily attributable to linguistic factors. Further exploration is warranted on the potential contribution of anatomical factors in F_0 differences in running speech, although the relevance of these factors was not strongly supported by the present data.

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Conflicts of interest
There are no conflicts of interest.

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