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Original Research Article

A comparative study of emphatic stress in patients with Parkinson's disease and age-matched controls

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ABSTRACT

Background: Stress is one of the suprasegmental aspects that endow with the overall shape to the word or sequence. Stress is likely to be the consolidation of each length and loudness, with the first two playing the greatest role. Parkinson's disease is a degenerative disorder of the central nervous system. Hypokinetic dysarthria characterized by monopitch, reduced stress, monoloudness, imprecise consonants, inappropriate silences, harsh voice and variable rate. The speech parameters most affected because of Parkinson's disease are articulation and suprasegmental features. Suprasegmental, or prosodic, speech characteristics are important in both the precise production and perception of speech. . This study is an attempt not only to illustrate the acoustic aspects of Parkinson's speech with reference to stress but also to express loading phenomenon with reference to stress aspects as measured in the frequency and time domain.

Methods: For this study two groups were chosen, Group I consisted of five normal participants and Group II consisted of five patients with Parkinson's disease. All the forty Bangla spondee words were chosen as stimulus for the purpose of the study. To analyse stress patterns in both the groups, Average f0, f0 slope, Average intensity, maximum intensity and duration of speech production task were chosen as parameters.

Results: Results revealed there were significant differences in all parameters between patients with PD and normal controls.

Conclusions: It can be concluded from the study that patients with PD demonstrate specific stress patterns in their speech as compared to age matched normals.

Keywords: Suprasegmentals, Parkinson's disease, Stress, Acoustic analysis

INTRODUCTION

In linguistics, stress is the degree of emphasis given to a sound or syllable in speech.[1] Here, Stress is operationally defined as emphatic stress. Emphatic stress is a stress whose functions are to focus, contrast, comment or comprise of new information. It contributes to detection of intonation patterns of a sentence.[2] Emphatic stress is one of the most robust measures of speech. This emphatic stress calls attention to the extraordinary nature of what one wants to emphasize. Suprasegmental of speech are important in both the precise production and perception of speech.[3] Stress is one of the suprasegmental aspects that endow with the overall shape to the word or sequence. Stress is likely to be the consolidation of each length and loudness, with the first two playing the greatest role.[4] It is the increased attempt for a change in the pattern of speech. This is signaled by an increased

modification the intensity, pitch duration and formant pattern. They are used to express the speaker's special intentions, which are hard to envisage without a deep understanding of the context.[5] A stressed syllable in a word is usually spoken with more articulatory force, resulting in a syllable i.e., louder, longer in duration and higher in pitch than an unstressed syllable. Stress in an utterance may serve various ways.

There are three elements of an utterance on which stress can occur a sentence, phrase, or word. Sentence stress, or prosodic stress, is used to emphasis certain part of a sentence. Phrasal stress helps differentiate phrases when their sequences of words are the same at the segmental level. Word stress describes the stress pattern on each syllable in a word. The stress patterns vary across languages. A stressed part of an utterance is usually perceived and distinguished by a listener as a louder part compared to the unstressed part.

On the other hand, from the standpoint of a speaker stress can be described as larger amount of effort given to speech production.6 In the domain of acoustics, stress in speech is usually described by three parameters: duration, fundamental frequency and intensity.[6,7] The fundamental vocal frequency that a speaker modulates to convey stress is considered to be the prominent parameter.[8,9] However, intensity and duration have been also showed to describe stress.[7,10-12]

Human's capability for oral communication probably evolved in parallel with the evolution of human brain. Trauma and disease have disrupted human's ability to communicate and have time after time understood the dependence of this skill on the integrity of the central and peripheral nervous system.[13] Speech is a highly complex motor act, a physiological process, requiring the coordination of respiration and articulation and is mediated by the nervous system.

Normal speech production requires the integrity and amalgamation of a number of cognitive, neuromuscular and musculoskeletal activities. There are three major neurologic process of speech production, which includes cognitive linguistic process, motor speech programming and neuromuscular execution. A lesion in any one of these stages can result in a motor speech disorder such as Dysarthria and Apraxia of speech.[14]

Parkinson's disease is a degenerative disorder of the central nervous system. PD is characterised by four major features tremor at rest, rigidity, bradykinesia and postural instability.[15] Furthermore, patients show diminished facial expressions and lack of associated movements, such as arm-swinging during walking. They have difficulties to initiate some movements and to terminate those.[16] A speech disorder develops in about 90% of PD cases.[17] The defects in motor function are caused by the progressive loss of dopaminergic neurons in the part of the brain called substantia nigra. In the normal state, dopaminergic effects decrease the inhibitory outflow of the basal ganglia. Therefore, the excitability of upper motor neurons is increased. When dopaminergic cells in the substantia nigra pars compacta are destroyed, the inhibitory flow becomes abnormally high.[16] Early in the course of the disease, the most apparent symptoms are movement related; these include shaking, slowness of movement, muscle rigidity and difficulty with walking and gait. Parkinson's disease often produces hypokinetic dysarthria, typified by imprecise articulation, prosodic abnormalities, disturbances of speech rate and low vocal volume.[18,19] The Mayo Clinic characterization of hypokinetic dysarthria emphasizes, in rank order, monopitch, reduced stress, monoloudness, imprecise consonants, inappropriate silences, harsh voice and variable rate.[19]

Overall incidence rates for PD in studies reported results for all age groups ranged between 1.5 and 22 per 1,00,000 person-years. Studies restricted to older populations (above 55 or 65 years) reported overall incidence rates between 410 and 529 per 1,00,000 person-years.[20] The speech parameters most affected as a result of Parkinson's disease are articulation and suprasegmental features.[14] Suprasegmental or prosodic, speech characteristics are important in both the precise production and perception of speech.[3] Stress is a suprasegmental aspect that endow with the overall shape to the word. If easy intelligibility is to be attained, it is important to give words to their proper stress.

In patients with Parkinson's disease, stress is the obvious phenomena as most of the patients suffer from dysarthria which cannot be solely treated with reference to medication such as L-Dopa.[21] There is a vivid need of research of stress with reference to acoustic means in patients with Parkinson's disease as these measures can be a significant of therapeutic markers in the practice of speech language pathology. Parkinson's disease associated with dysarthria shows variable stress pattern with reference to increase of speaking in longer duration as measures of loading.

This study is an attempt not only to illustrate the acoustic aspects of Parkinson's speech with reference to stress but also to express regarding loading phenomenon with reference to stress aspects as measured in the frequency and time domain. Though perceptually well established, there have not been much studies regarding acoustic standardization of emphatic stress parameters in Bangla language.

This will help speech language pathologists for intervening the overall speech intelligibility of PD patients. Therefore, there is a need for the analysis of stress for those populations there by reducing variability in analysis as compared to perceptual analysis. The aim of the present study was to compare the acoustic features for analysis of emphatic stress between patients with Parkinson's disease and age matched normal controls.

METHODS

Research design

The study utilized Cross-sectional comparative study design using convenience sampling method.

Participants

A total of 10 participants aged between 30 years to 75 years with mean age of 37.4 and SD of 3.53 were included for the study. All the participants had a good proficiency in Bengali. The participants were divided into two groups. The PD patients were taken from Neurology department of Institute of Neurosciences, Kolkata. The Speech, Language, Hearing and cognitive functioning of all the participants were assessed in AYJNISHD (D), Kolkata. The study was carried out from February'26 to August'26.

Group I consisted of five normal participants

Inclusion criteria

All participants had hearing sensitivity within normal limits and follow normal conversational speech and had no history of speech and language disturbances as diagnosed by Audiologist and Speech Language pathologist. None of the patients had a history of substance abuse, medical complications or had undergone brain surgery of any sort. Group II consisted of five patients with Parkinson's disease (PD). All the participants with PD were diagnosed by neurologists and were under medication (L-dopa) for 2 years as suggested by neurologist.

Inclusion criteria

None of the patients had history of substance use, other medical or neurological difficulties other than PD. Prior to testing, each PD participant was screened for language ability, cognition, mood and executive functions. The absence of formal language impairment like aphasia was indicated by a speech language pathologist. The presence and type of dysarthria was assessed and confirmed using the Franchy Dysarthria Assessment (FDA). The degree of dysarthria was confirmed using the Dysarthria Severity Index. Apraxia of speech was ruled out using Apraxia battery of adults (ABA).

They had a good hearing as needed to comfortably follow conversational speech. A detailed psychological evaluation was done by a psychologist to eliminate chances of memory loss or dementia using the AIIMS-neuropsychological battery. None of the patients had any sort of articulation errors except distortion errors in some consonants, which was due to oro-muscular weakness. None of the patients underwent speech therapy of any kind regarding Parkinson's disease.

Instrumentation

Acoustic analysis was done using Praat software version 5.2.01 using HP personal laptop with Microsoft windows 10. High fidelity microphone i.e. Sennheiser Electret condenser microphone (Sennheiser HD 201) was used for recording. The recording were done at mono recording mode as given in the Praat software. The sampling frequency was fixed at 44100Hz.

Stimulus

All the forty Bangla spondee words were chosen as stimulus for the purpose of the study. Spondee words were selected for the study, as those are bisyllabic words having equal stress on both the syllables.

Procedure

Phase-I (Demonstration of pre-recording trials)

All the spondee words were presented to the participants for the familiarization with the test procedure.

Phase-II (Presentation of test stimulus)

Words presented to the participants were written on a card. Participants were informed about the nature of the study and their written consent was obtained. Participants were instructed to speak the whole spondee words all at a time in the demonstrated manner. All the forty words were recorded thrice. Of the three samples, only the best was considered for further analysis. Speech samples of the participants were recorded individually.

Phase-III (Recording of stimulus)

Each participant was seated in a soundproof room to eliminate any external noise. The distance between the mouth and the microphone was kept constant at approximately 10 cm. A wideband spectrograph thus obtained was analysed using PRAAT software for this study. Then a portion of the recorded sample was selected to analyse. Each word of each spondee was truncated from the whole recording and were analysed separately. The selected segment was shown by a rectangular pink shape surrounding it. Then the first word was selected creating a blue vertical line, demarcating the onset of the first word and the end of the word was marked by moving the cursor. The selected signal was then analysed for fundamental frequency, intensity and duration.

Data analysis

The data analysis was done for isolated spondee words. To analyse stress patterns in two syllables of spondee words, two frequency related parameters (Average f0, f0 slope), two intensity parameters (Average intensity and maximum intensity) and duration of word pair parameters were chosen. The spectrographic profile of different word

occurrence were analysed for the features mentioned above.

Statistical analysis

All the statistical analyses for the present study were performed using SPSS20 software. One way ANOVA was used with the significance level set at 95% to assess the significant differences in acoustic features of stress between two groups.

RESULTS

The mean score was calculated for each parameter of each syllable and the difference in their mean was obtained. One way ANOVA was done to obtain the significant difference in acoustic features of stress in patients with Parkinson's disease and age matched normals.

Table 1 reveals mean and standard deviation of f0 between normals and patients with Parkinson disease. One way ANOVA was done to compare between two groups which reveals there is significant difference in f0 between two groups, p=0.000919 (p<0.05, df=1) with F value of 26.10, which is reflected in Table 2.

Table 3 shows mean and standard deviation of difference in rate of f0 change (f0 slope) in Hz between normals and patients with Parkinson disease. One way ANOVA was done to compare between two groups which reveals there was significant difference in f0 slope between two groups, p=0.017 (p<0.05, df=1) with F value of 8.99, which is depicted in Table 4.

Table 5 illustrates mean and standard deviation of average intensity in dB between normals and patients with Parkinson disease. One way ANOVA was administered to compare between two groups which revealed there was significant difference in average intensity between two groups, p=0.000 (p<0.05, df=1) with F value of 83.71034, which is shown in Table 6.

Table 7 shows mean and standard deviation of maximum intensity in dB between normals and patients with Parkinson disease. One way ANOVA was done to compare between two groups which reveals there is significant difference in maximum intensity between two groups, p=0.00124 (p<0.05, df=1) with F value of 135.414, which is reflected in Table-8.

Table 9 displays mean and standard deviation of duration of each spondee word in seconds between normals and patients with Parkinson disease. One way ANOVA was conducted to compare between two groups which reveals there was significant difference in duration of each spondee word between two groups, p=0.0001 (p<0.05, df=1) with F value of 13.24807, which is shown in Table 10.

Table 1: Mean and standard deviation of f0 between normals and patients with PD.

Groups	Count	Sum	Average	SD
Normal	5	652.4	130.48	10.51
PD	5	515.42	103.084	5.76

Table 2: Comparison of f0 values between normals and patients with PD.

Source of variation	SS	df	MS	F	P value
Between groups	1876.352	1	1876.352	26.10964	0.000919
Within groups	574.9147	8	71.86434		
Total	2451.267	9			

Table 3: Mean and standard deviation of f0 slope between normals and patients with PD.

Groups	Count	Sum	Average	SD
Normal	5	70.66	14.132	4.13457
PD	5	53.03	10.606	2.77808

Table 4: Comparison of f0 slope between normals and patients with PD.

Source of variation	SS	df	MS	F	P value
Between groups	31.08169	1	31.08169	8.992699	0.017103
Within groups	27.6506	8	3.456325		
Total	58.73229	9			

Table 5: Mean and standard deviation of average intensity between normals and patients with PD.

Groups	Count	Sum	Average	SD
Normal	5	302.01	60.402	11.21132
PD	5	223.3	44.66	3.59035

Table 6: Comparison of average intensity between normals and patients with PD.

Source of variation	SS	df	MS	F	p value
Between groups	619.5264	1	619.5264		
Within groups	59.20668	8	7.400835	83.71034	0.000
Total	678.7331	9			

Table 7: Mean and standard deviation of maximum intensity between normals and patients with PD.

Groups	Count	Sum	Average	SD
Normal	5	329.1	65.82	1.6798
PD	5	241.36	48.272	2.56492

Table 8: Comparison of maximum intensity between normals and patients with PD.

Source of variation	SS	df	MS	F	p value
Between groups	769.8308	1	769.8308		
Within groups	16.97888	8	5.685	135.414	0.00124
Total	786.8096	9			

Table 9: Mean and standard deviation of duration between normals and patients with PD.

Groups	Count	Sum	Average	SD
Normal	5	1.99	0.398	0.00067
PD	5	1.16	0.232	0.00037

Table 10: Comparison of duration between normals and patients with PD.

Source of variation	SS	df	MS	F	p value
Between groups	0.06889	1	0.06889		
Within groups	0.00416	8	0.0052	13.24807	0.0001
Total	0.07305	9			

DISCUSSION

The present study was conducted to compare stress production between individuals with Parkinson's disease (PD) and age-matched healthy controls in Bengali. The findings indicate differences in stress production between the two groups, suggesting that Parkinson's disease may affect the ability to produce appropriate acoustic contrasts between stressed and unstressed speech units. These findings are consistent with the broader understanding that speech in individuals with PD may be characterized by reduced vocal intensity, restricted pitch variation, imprecise articulation, altered speech rate and abnormalities in prosody.[18,19] The differences observed in the present study may reflect the influence of Parkinsonian motor dysfunction on the coordination and regulation of the physiological mechanisms involved in speech production.

One of the important findings of the present study is the significant difference in f0 slope between the individuals with PD and the healthy control group. f0 slope represents the rate and direction of change in fundamental frequency over a specified time interval. It provides information about how rapidly pitch rises or falls during the production of a syllable or word. In stress production, changes in f0 may contribute to the perceptual prominence of a particular linguistic unit. A steeper f0 contour may indicate a more pronounced pitch movement, whereas a relatively shallow contour may reflect reduced pitch modulation. The significant difference in f0 slope observed between the two groups therefore suggests that individuals with PD may have difficulty generating the pitch movements required to express stress effectively. These findings are in congruent with the findings of the study done by Fumel et al.[22] The reduced or altered f0 slope in individuals with PD may be

associated with the motor abnormalities characteristic of the disease.

Fundamental frequency is particularly relevant to the present study because it contributes to the perception of prominence in many linguistic contexts. Nevertheless, f0 should not be considered the sole determinant of stress. Speakers may also use changes in intensity, duration, spectral characteristics and voice quality to distinguish stressed syllables from unstressed ones. In individuals with PD, these acoustic cues may be affected to different degrees because the underlying physiological mechanisms are not identical. For example, reduced respiratory support may contribute to lower vocal intensity, while impaired laryngeal control may affect pitch modulation. Similarly, abnormalities in the timing and coordination of speech movements may influence syllable duration. The combined effect of these changes may reduce the acoustic contrast between stressed and unstressed syllables and thereby alter the overall prosodic pattern of speech.[23] The present findings may also be interpreted in relation to the reduced energy and movement amplitude frequently associated with Parkinsonian motor dysfunction. Ladefoged discussed the relationship between articulatory and acoustic properties in speech production, and the production of prominence often involves coordinated changes in several acoustic dimensions. However, stress should not be understood as a direct measurement of physical energy alone. Rather, it results from the interaction of multiple acoustic and linguistic cues. If the ability to modulate vocal intensity, pitch, and timing is reduced, the acoustic realization of stress may become less distinct. This interpretation provides a possible explanation for the differences in stress-related acoustic measures observed between the PD and control groups.

Respiratory dysfunction may represent another factor contributing to the observed differences. Speech production depends on an adequate and relatively controlled airflow from the lungs to support phonation. Solomon and Hixon described respiratory abnormalities associated with Parkinson's disease, including changes in the contribution of the rib cage to lung-volume variation.[24] Alterations in respiratory function may affect the availability and regulation of the airflow required for sustained and appropriately modulated speech. Inadequate respiratory support may contribute to reduced vocal intensity and may limit the speaker's ability to produce prominent syllables with sufficient acoustic contrast. However, respiratory function alone cannot fully explain alterations in F0 slope, because pitch modulation also depends on laryngeal control and the coordination of multiple speech subsystems. Thus, the differences observed in the present study may reflect the combined effects of respiratory, phonatory and motor-control abnormalities.

The role of intensity in stress production is also important when interpreting the findings. In typical speech, stressed syllables may be produced with greater intensity than unstressed syllables, thereby enhancing their perceptual prominence. Individuals with PD frequently exhibit hypophonia, which is characterized by reduced vocal loudness. Reduced intensity may therefore limit the degree to which stressed syllables are distinguished from their surrounding speech units. However, an overall reduction in vocal intensity does not necessarily imply a proportional reduction in the intensity difference between stressed and unstressed syllables. For this reason, stress-related intensity contrasts should ideally be examined in addition to absolute intensity values. Such an approach would help distinguish a general reduction in vocal loudness from a specific impairment in the acoustic marking of stress.[25]

Duration is another important acoustic parameter that may contribute to the production of stress. Stressed syllables are sometimes longer than unstressed syllables, although the extent of this difference depends on the language, phonetic context, and type of stress being examined. Changes in speech timing associated with PD may influence the duration of individual syllables and the temporal organization of an utterance.[25] Nevertheless, the presence of an overall change in speech rate does not necessarily indicate an equivalent change in stress-related duration contrasts. A more detailed analysis of the relative duration of stressed and unstressed syllables would therefore be useful for determining whether temporal marking is also affected in Bengali-speaking individuals with PD.

An important aspect of the present study is its focus on Bengali, which provides an opportunity to investigate the effects of Parkinson's disease on stress production within a specific linguistic system. Prosodic patterns vary across languages, and the acoustic cues used to convey prominence may differ according to linguistic structure and communicative context. Consequently, findings from studies conducted in other languages cannot always be generalized directly to Bengali. The differences observed in the present study suggest that Parkinson's disease may influence the acoustic realization of stress in Bengali speech. Further investigation is required to determine how these differences interact with the phonological and prosodic characteristics of Bengali, including word structure, syllable position and the placement of emphasis within an utterance.

The clinical implications of these findings are also noteworthy. Speech assessment in individuals with PD often focuses on vocal intensity, articulation, voice quality, and speech intelligibility. However, the present findings indicate that stress-related acoustic parameters, particularly F0 slope, may provide additional information about prosodic impairment. Reduced or altered pitch modulation may affect the listener's ability to identify the intended prominence of words and may influence the naturalness and communicative effectiveness of speech. Therefore, the assessment of F0, F0 slope, intensity and

duration may contribute to a more comprehensive understanding of speech difficulties associated with Parkinson's disease. These measures may also be useful in monitoring changes in speech production over time, provided that they are interpreted alongside perceptual assessments and relevant clinical information.

From a therapeutic perspective, the findings highlight the potential importance of addressing prosodic control as part of speech-language intervention for individuals with PD. Depending on an individual's specific speech profile, intervention may include activities targeting pitch variation, vocal intensity, appropriate stress placement, and the production of clear contrasts between stressed and unstressed syllables. Such approaches should be individualized and evaluated using both acoustic measurements and listener-based outcomes. The present study does not establish the effectiveness of any particular intervention, but it provides a rationale for considering stress production as one component of a comprehensive assessment of Parkinsonian speech. Despite these findings, certain considerations are necessary when interpreting the results. Acoustic measurements may be influenced by factors such as age, sex, disease severity, medication status, vocal characteristics, speech task and the linguistic context in which the stimuli are produced. The number of participants and the representativeness of the sample may also influence the generalizability of the findings. Furthermore, a statistically significant difference in F0 slope does not automatically establish the magnitude of its clinical impact. The relationship between acoustic differences and listeners' perception of stress should therefore be examined directly. Future studies could include larger samples, more diverse speech tasks, and additional measures of F0 range, intensity contrast, syllable duration and speech timing. Investigating the relationship between these acoustic parameters, disease severity and perceptual judgments would help clarify the nature and extent of prosodic impairment in Bengali-speaking individuals with PD.

CONCLUSION

The findings of the present study suggest that the acoustic realization of stress in Bengali spondee words may be affected by the motor, respiratory and phonatory changes associated with Parkinson's disease. Alterations in pitch modulation, intensity and duration may reduce the acoustic distinction between stressed and unstressed syllables. These findings highlight the importance of assessing suprasegmental features in individuals with Parkinson's disease and emphasize the need for further research on language-specific stress patterns using larger sample sizes.

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