Laryngeal and Supralaryngeal Manifestations of the Speech of Stutterers - A Spectrographic Study

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Abstract

Stuttering is a communication disorder affecting the fluency of speech. The cause of stuttering has been debated for many years and has been attributed to psychological, neurophysiological (spasticity), genetics, and environmental factors. The effect of stuttering is multifaceted. There can be incoordination /spasm /tension in the muscles of the subsystems of speech production like respiratory, laryngeal, and articulatory, often accompanied by anxiety, which can vary from patient to patient.

The aim of the study was to check whether these are reflected in the spectrographic analysis of the speech of the stutterers.

Methodology

This observational study consisted of 10 severe stutterers between the age range of 15 to 25 years and 10 normal subjects matched for age and sex.

The following acoustic parameters were extracted from the spectrogram.

1. Formant frequencies - F1, F2, and F3
2. Transition duration: (Fl, F2)
3. Voice onset time

Results

The results of our study revealed that stutterers differed significantly from nonstutterers in terms of the spectrographic parameters of transition duration and Voice onset time. There was no significant difference between stutterers and normal subjects for Formant frequency (Fl, F2, and F3).

Conclusion

The results showing no significant difference in formant frequencies but a significant difference in formant transition between stutterers and nonstutterers suggests that the stutterers have normal vocal tract, but abnormal vocal tract adjustments occur during formant transitions from one speech sound to the next.

Keywords: Stuttering, spectrogram, laryngeal and supralaryngeal mechanism

Stuttering is a communication disorder affecting speech fluency characterized by involuntary repetition or prolongation of sounds, syllables, or words or by involuntary hesitation or pauses that disrupt the smooth, rhythmic flow of speech (ICD-11; World Health Organization, WHO, 2022). (1) Though the exact cause of stuttering is unknown, psychological (logophobia – fear of speaking), neurophysiological (spasticity), genetics, and the environment have been suggested to be contributing factors. (2–8)

The effect of stuttering is multifaceted. There can be incoordination /spasm /tension in the muscles of the subsystems of speech production like respiratory, laryngeal, and articulatory, often accompanied by anxiety, which can vary from patient to patient.

The aim of the study was to check whether these are reflected in the spectrographic analysis of the speech of the stutterers. A spectrogram is a three-dimensional visual representation of the distribution of acoustic energy across frequencies and over time; the vertical axis is frequency, the horizontal axis is time, and amplitude is shown on a grey scale.

Objectives of the study

To do a spectrographic analysis of the speech of the stutterers.

Methodology

Participants

This observational study consisted of 10 severe stutterers diagnosed based on stuttering severity instrument (9)between the age range of 15 to 25 years and 10 normal subjects matched for age and sex. The normal subjects had no history of speech difficulty.

Consents were taken concerning the participation in the study after explaining the details of the study.

Procedure

The subjects were seated comfortably in a sound-treated recording room with an average noise level of around 40 dB. The reading of the Rainbow Passage (9) by the subjects was audio recorded using a digital recorder (Sony IC Recorder, ICD-PX440). It is a standard oral reading passage used by speech-language pathologists. The microphone was held approximately 10 cm from the mouth of the subjects during the recording. The speech samples were recorded at a sampling rate of 44,100 Hz and with 16-bit quantization. The Vaghmi software (Speech and Voice Systems, Bangalore, India) was used to analyze data, which is an indigenous software developed for the objective analysis of speech and Voice.

The following acoustic parameters were extracted from the spectrogram.

1. Formant frequencies - F1, F2, and F3
2. Transition duration: (Fl, F2)
3. Voice onset time

The formants F1, F2, and F3 of the vowels “a," "I," "e," u," and "o" were extracted from the words “end," "gold," "prism," "arch” and “beautiful” of the reading sample of the rainbow passage. The voice onset time of “p," "t," "k," "b," "d," "g” were extracted from the words “path," "take," "above," "division” and “gold."The visual display of the speech was correlated with the auditory form of the sample, and the words were identified and selected.

1. Formant frequencies - F1, F2, and F3: Midpoint of the visible dark energy bands appropriate to the first three vowel resonances.

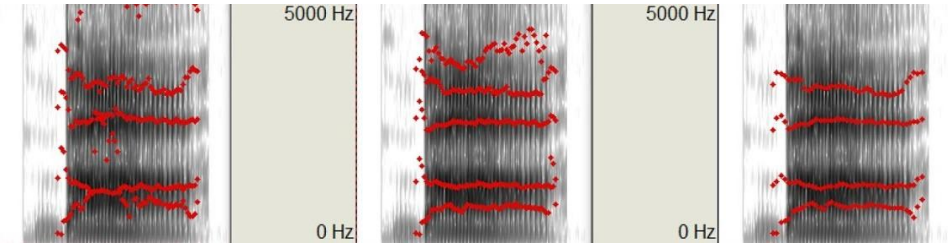

Fig 1. Formant frequencies

2. Transition duration: (Fl, F2) - Time between the (vowel onset) onset of transition of formant and the termination of the transition. Transition in the formant frequency reflects the change in the shape and, in turn, the resonance of the vocal tract. Vowel onset is defined as the first glottal pulse after the release burst of the preceding stop consonant. (10)

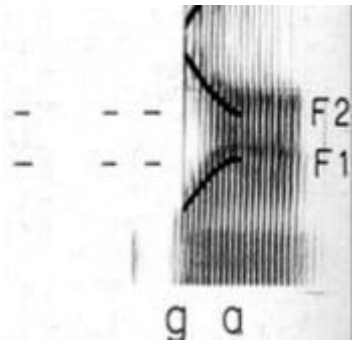

Fig 2. Transition duration of Formant frequencies

3. Voice onset time: Voice onset time is the duration between the burst and the subsequent onset of voicing of the following vowel.

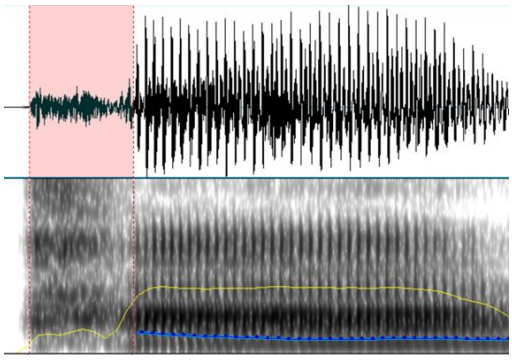

Fig 3. Voice onset time

Statistical Analysis

Wilcoxon matched-pairs signed ranks test was done to find out the significant difference between stutterers and nonstutterers.

Results

The mean and standard deviation of the formant frequencies F1, F2, and F3 for the vowels "a,"" i,"" e," "u," and "o" were calculated for both stutterers and normal subjects (Table 1). The

analysis of variance indicated no significant difference between stutterers and normal subjects. (Table2)

Forman t frequencies -Normals			**Formant frequencies -stutterers**	
	Mean	**SD**	**Mean**	**SD**
F1 for a	927.22	10.75	758.98	54.28
F2 for a	1072.0	21.96	1139.12	166.74
F3 for a	2442.2	7.05	2498.72	200.3
F1 for e	496.06	39.1	442.92	30.74
F2 for e	1762.2	212.4	1618.40	486.3
F3 for e	2553.8	344.4	2650.00	199.08
F1 for i	271.54	15. 55	265.6	36.46
F2 for i	2183.8	75.49	2338.36	93.3
F3 for i	2816	144.7	2952.6	381.28
F1 for o	485	11.4	479.72	39.93
F2 for o	937.18	25.52	955.2	43.21
F3 for o	1752	131.62	1780.2	203.39
F1 for u	335.76	25.42	333.04	20.24
F2 for u	940.1	30.09	991.26	93.31
F3 for u	2163.54	166.76	**2239.54**	**226.11**

Table 1. Showing Mean and Standard Deviation of Formant Frequencies

Format frequencies (Fl)

	Z valu e	P valu e	Significanc e
a	**-0.5002**	**0.6742**	**-**
i	**-0.4045**	**0.6858**	**-**
e	**-0.0796**	**-1.7529**	**-**
u	**-0.1348**	**0.8927**	**-**
0	**-0.4045**	**0.6858**	**-**
Formant Frequencies (F2)			
a	**-0.4045**	**0.6858**	**-**
i	**-0.1348**	**0.8927**	**-**
e	**-0.0431**	**2.0226**	**-**
u	**-0.4045**	**0.688**	**-**
0	**-0.0796**	**1.7529**	**-**
Formant Frequencies (F3)			
a	**-0.4045**	**0.6858**	**-**
i	**-0.1348**	**0.8927**	**-**
e	**-0.5002**	**0.6742**	**-**
u	**-0.4045**	**0.6858**	**-**
0	**-0.1348**	**0.8927**	**-**

Table 2. Comparison of stutterers and nonstutterers in terms of formant frequencies using Willcoxin' s matched pair s test.

The mean and standard deviation of the transition duration of the formant frequencies F1 and F2 for the vowels "a,"" i,"" e," "u," and "o" were calculated for both stutterers and normal subjects (Table 3). The analysis of variance indicated significant differences between stutterers and normal subjects. (Table 4)

Transition duration- Normals			**Transition duration -stutterers**	
	Mean	**SD**	**Mean**	**SD**

F1 for a	41	9.48	95.8	6.05
F2 for a	53.8	12.7	128.6	8 .98
F1 for e	40.4	2.7	198.2	9.49
F2 for e	29.9	3.7	117.8	5.6
F1 for i	48.8	4.97	95.4	4.87
F2 for i	55.4	4.83	120.6	3.71
F1 for o	23.4	3.97	59	6.24
F2 for o	39.4	3.8	62	5.8
F1 for u	21.8	16. 5	106	36.03
F2 for u	31	4.3	90	4.5

Table 3. Showing transition duration (Mean and Standard Deviation)

Transition duration (Fl)	**Z valu e**	**P value**	**Significance e**
a	**-2.0226**	**0.0431**	+
i	**-2.0319**	**0.0422**	+
e	**-2.0226**	**0.0431**	+
u	**-2.0226**	**0.0431**	+
0	**-2.0412**	**0.0412**	+
Transitio n duration n (F2)			
a	**-2.0226**	**0.0431**	+
i	**-2.0226**	**0.0431**	+
e	**-2.0226**	**0.0431**	+

u	**-2.0226**	**0.0431**	+
o	**-2.0226**	**0.0431**	+

Table 4: Comparison of stutterers and nonstutterers in terms of transition durations using Willcoxin's matched pairs test.

The voice onset time values for “p," t," k," "b," "d," and "g” were calculated for both stutterers and normal subjects. The voice onset time values were higher for the stutterers than for normal subjects. The mean and standard deviation are given in Table 5. The analysis of variance indicated significant differences between stutterers and normal subjects. (Table 6)

	VOT - Normals		**VOT - stutterers**	
	Mean	**SD**	**Mean**	**SD**
VOT 'p'	**11.55**	**4. 51**	**96.13**	**3.24**
VOT 't '	**15.29**	**4.21**	**41.7**	**18 .36**
VOT 'k'	**25.78**	**3.20**	**66.59**	**2.70**
VOT 'b'	**-89.42**	**1.448**	**-104.82**	**3.94**
VOT 'd'	**-94.54**	**4.32**	**-125.48**	**2 .43**
VOT 'g'	**-87.89**	**1.511**	**-90.34**	**4.076**

Table 5 shows the Mean and Standard Deviation for VOT.

	Z value	**P value**	**Significance**
P	**-2.0226**	**0.0431**	+
t	**-1.7529**	**0.0796**	+
k	**-2.0226**	**0.0431**	+
b	**-2.0226**	**0.0431**	+
d	**-2.0226**	**0.0431**	+
g	**-1.2136**	**0.2249**	+

Table 6. Comparison of stutterers and nonstutterers in terms of VOT using Willcoxin's matched pair s test.

Discussion

There was no significant difference in formant frequencies but a significant difference in formant transition between stutterers and nonstutterers. The vocal cord vibrations produce a complex periodic wave (pressure fluctuation) whose spectrum contains energy at the fundamental frequency and multiples of the fundamental frequency called harmonics. The vocal tract acts as a filter. The complex periodic waves produced by the vocal cords are filtered by the resonance characteristics of the vocal tract, giving rise to formant frequencies, which appear as a frequency peak in the voice spectrum.

Formant frequencies reflect the filter function of the vocal tract. The column of air in the vocal tract has specific natural modes of vibration or resonances based on its size and shape, and hence, the length and shape of the vocal tract determine the formant frequencies of speech sounds. The formant frequency (steady-state) reflects a fixed vocal tract posture specific to the vowel. (9). The formant transition reflects changes in vocal tract shape (11). The results showing no significant difference in formant frequencies but a significant difference in formant transition between stutterers and nonstutterers suggests that the stutterers have normal vocal tract, but abnormal vocal tract adjustments occur during formant transitions from one speech sound to the next.

There was a significant difference in Voice onset time between stutterers and nonstutterers. Voice Onset Time (VOT) is the temporal relationship (duration) between the release of a plosive and the beginning of vocal fold vibration, measured in milliseconds(12). This reflects the physiological incapability for the movement of vocal cords from the abducted position to the adducted position and also the increased time taken by the articulators from the placement for production of “stops/ plosive” to the position of vowel “a” in stutterers. Ward’s study on three stuttering subjects showed that voice-onset time (VOT) in the fluent utterances of stuttered speech is slower than those of their normal-speaking peers. (13) .It has been reported that stutterers produced, even during nonstuttering periods, an enhanced variation of voice onset time and an increased variability for the duration of phonation (14).

Our results agree with the theories of Yates and Arnott, who wrote that the common cause of stuttering is the spasmodic interruption in the glottis, affecting all the articulations. (15–17).

Conclusion

The results of our study revealed that stutterers differed significantly from nonstutterers in terms of the spectrographic parameters of transition duration and Voice onset time. There was no significant difference between stutterers and normal subjects for Formant frequency (Fl, F2, and F3).

The results showing no significant difference in formant frequencies but a significant difference in formant transition between stutterers and nonstutterers suggests that the stutterers have normal vocal tract, but abnormal vocal tract adjustments occur during formant transitions from one speech sound to the next.

The above findings indicate that the laryngeal and supralaryngeal mechanisms during speech are different for stutterers compared to those of nonstutterers. Whether these differences in laryngeal and supralaryngeal mechanisms can be attributed as a cause for stuttering or as an effect of stuttering needs further research.

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