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An acoustical analysis of the vowel space area of patients with mild spastic dysarthria due to cerebral infarction

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Abstract
Objective: The purpose of this study is to analyze the characteristics of vowel space by schematizing each vowel's formant specifically in patients with mild spastic dysarthria.
Materials and Methods: The subject group consisted of 21 mild dysarthria patients and the 21 control. We had them perform phonation of the vertex vowels of a vowel quadrangle /a, i, u. æ/. To analyze the area of vowel space, F1 and F2 were measured.
Results: There were statistically significant differences when comparing the vowel /a/ of F1(733.7) and comparing the vowel /æ/ of F2(831.1) (p<0.05).
The area of vowel space of patients with dysarthria (240775.3) was significantly narrower than control (318258.7) (p< 0.05).
Conclusion: Mild dysarthria require a therapeutic intervention with emphasis on resonance cavities or vocalization becuase the use of resonance is low and the burden of speech generation is increased.

Keywords: dysarthria, speech disorders, speech acoustics

Introduction
Dysarthria occurs due to an abnormality of the central or peripheral nervous system that weakens the muscular movement ability that is necessary for speech production. This disease typically is characterized by a slow rate of speech, inappropriate coordination, and decreased range of motion [1]. Although the symptoms of dysarthria differ depending on which neural area is damaged, it mainly causes problems in breath, vocalization, resonance, modulation, and cadence, which affect the quality and articulation of speech. Therefore, people suffer difficulties in speech, which is the most important part of communication.
Among several types of dysarthria, spastic dysarthria is the most common and occupies a large portion in the clinical field [1]. The characteristics of spastic dysarthria are vocalization problems, such as a strained-strangled voice or harsh sounds with short breath, and low consonant accuracy; modulation problems, such as vowel distortion; resonation problems, such as temporary hyper-nasality; intonation problems, such as monotone or decreased range of tone; and others [2].
The articulation in clinical studies is most often evaluated by a speech therapist's subjective analysis. A speech therapist listens to the patient's voice and judges the articulation of phonemes. Since the voice can be interpreted differently depending on the conditions of speaker and listener, it is not a quantitative way to examine the voice [3]. Previous research has shown that the ability to predict the meaning of a message affects the listener's determination. The length of a speech influences the listener's concentration and the ability to interpret meanings [4, 5]. Research has also shown that the context, circumstances, and characteristics of a listener (professionalism, familiarity with a speaker, experiences, etc.) can affect the determination of articulation [6].
In order to address these problems, we need to analyze the vowel space, which is an acoustics analysis method that evaluates the voice quantitatively and objectively. In a vowel space, the shape of the vocal tract is transformed into a two-dimensional field through the formant of a vowel, so it reflects the location of an articulator.
A rectangular vowel diagram is connected by the coordinates of a vertex vowel in F1-F2 space using the F1 (the first formant) and F2 (the second formant) of the vowel.

The area of vowel space can be calculated by obtaining the area of the space formed in a rectangular diagram [7] (Figure. 1). The area of vowel space is related to the articulation of speech. Various research findings have shown a positive correlation between the area of vowel space and the clarity of speech. As the area of vowel space gets larger, the speech shows higher clarity [8, 9, 10].

These rectangular vowel diagrams examine the movement of articulators that produce the vowel by using /a/, /i/, /u/, /æ/ from English and F1, F2.

According to studies of the differences between vowels of the English and Korean languages, Korean vowels have a triangular instead of a rectangular form, due to the different sound of /æ/ [11]. Another study found that compared to normal people, patients with spastic dysarthria show decreased vowel space area and reduced clarity on all four vowels from a rectangular vowel diagram [12]. However, it has not been reported which vowel shift decreases the area or what kinds of partial changes in articulation occur in minor disorders. The purpose of this study is to analyze the characteristics of vowel space by schematizing each vowel's formant specifically in patients with spastic dysarthria, and to describe the results quantitatively.

Materials and Methods

The subject group of this study consisted of 21 patients with dysarthria treated at university hospitals in the Busan region from May 2017 to June 2018. The control group consisted of 21 normal adults without dysarthria. The patients suffered dysarthria because of a bilateral cerebral infarction, which was diagnosed by brain magnetic resonance imaging interpreted by neurologist. Their ages ranged from 22 to 84 years. We classified spastic dysarthria based on the Duffy standard, and selected patients with mild dysarthria according to the articulation ability index suggested in Lee Ok-bun's research (2010) [1, 13]. In addition, we used the Korean Western Aphasia Battery (K-WAB) to identify patients who could communicate smoothly in daily life. These patients were assigned to the normal group.

The patients who had dysarthria due to causes other than cerebral infarction, such as cerebral hemorrhage or Parkinson's disease, were excluded from this study, as were patients who had aphasia. Patients who had different types of dysarthria other than spastic and those who could not be tested because of cognitive decline were also excluded. We included normal adults aged from 20 to 50 years who had no history of diagnosis of brain lesions such as stroke or transient ischemic attack. We also checked the normal patients' articulation ability index to rule out dysarthria.

Assessment

To collect the speech samples of the patients with dysarthria, we had them perform phonation of the vertex vowels of a rectangular vowel diagram /a, i, u. æ/ for 5 seconds. Patients rehearsed beforehand to carry out comfortable phonation. The speech samples were collected using a portable voice recorder (R-09HR) in a silent room. The sampling rate was adjusted to 44,000 Hz and the recorded voices were saved as.wav files and analyzed by a voice program CSL.

To analyze the area of vowel space, F1 and F2 were measured. We selected the clearest and most stable 3 seconds in the middle out of the extended phonation time of each vowel. With F1 and F2, the area of vowel space was calculated with the method of Higgins and Hodge (2002) [14].

Area=0.5(F1/i/×F2/u/-F1/u/×F2/i/)+0.5(F1/u/×F2/a/-F1/a/×F2/u/)+0.5(F1/a/×F2/æ/F1/æ/×F2/a/)+0.5(F1/æ/×F2/i/-F1/i/×F2/æ/)

Statistical analysis

Descriptive statistics were performed to calculate the average and standard deviation of F1 and F2 in spastic dysarthria, with SPSS version 22.0 software (SPSS Inc., Chicago, IL). An independent sample t-test was also conducted to compare the areas of vowel space of patients with dysarthria with those of normal adults.

Results

The vowel formant of patients with dysarthria

Table 1 presents the results for each different vowel for F1 and F2. There were statistically significant differences between the mild dysarthria group and the normal control group (Table 1) when comparing the vowel /a/ of F1 and comparing the vowel /æ/ of F2 ($p<0.05$) . In vowel /a/, the average value of F1 was 733.7 in the mild dysarthria group and 831.1 in the control group. The average value of F2 in /æ/ was 1800.4 in the mild dysarthria group and 2079.7 in the control group. For vowel /i/, the average values of F1 and F2 in the mild dysarthria group were 355.1 and 2168.4, respectively, whereas in the control group they were 326.9 and 2339.9, respectively; there were no significant differences between groups. In vowel /u/, the average values of F1 and F2 in the mild dysarthria subject group were 400.6 and 878.5, respectively, whereas in the control group they were 391.3 and 910.2, respectively; again, there were no significant differences between groups.

The relationship between the vowels' F1 and F2

We schematized the formants using the four vowels' F1 and F2 of the mild dysarthria group and the control group (Figure 2). The coordinate point of vowel /u/ of the control group was on a similar location with the point from the mild dysarthria group. The coordinate points of vowel /a/ were spread widely on the bottom of the left side, and those of vowels /æ/ and /i/ were on the upper part of the left side. As in Figure 2, the four vowels from the control group and from the mild dysarthria group formed nearly triangular structures.

The area of vowel space

The areas of vowel space, as shown by four vowels of F1 and F2, were compared in the mild dysarthria group and in the control group. The area of vowel space of patients with dysarthria was significantly narrower than that of normal adults ($p< 0.05$) (Table 2).

Discussion

Dysarthria is a speech disorder that features a functional disorder in initiation, control, and coordination of articulatory structures involved in speech output [15]. Previous study, it was observed in 8%–30% of patients who had large stroke series [16]. Among the large stroke series, dysarthria was a common symptom of cerebral ischemia. The study found that 52.9% of the patients with classic lacunar stroke syndrome had dysarthria, and it was closely related to small vessel disease. In addition, the infarction region associated with dysarthria was found most commonly in the pons (30.9%), centrum semiovale (23.5%), and primary motor cortex (5.9%). Dysarthria was also associated with isolated cerebellar infarction.

In this study, we examined the characteristics of vowels and the area of vowel space. We calculated these through an acoustical analysis of the vowels from patients who developed mild dysarthria after cerebral infarction regardless of the region, and compared the results with those of normal adults.

In other study, that did not select a particular grade of dysarthria, there were differences between patients with spastic dysarthria and normal controls in all four vowels /a/, /æ/, /i/, and /u/, and the area of vowel space was 158,492 [12]. In our research, which only included patients with mild dysarthria, the patient group showed a significant difference only in certain vowels compared to the control group. Patients with mild dysarthria showed significantly higher values of F1 vowel /a/ compared with normal group. At the same time, patients with mild dysarthria showed significantly lower values for vowel /æ/ F2 compared with normal group. In addition, for the vowels /i/ and /u/, there were no differences in formant. The area of vowel space was 240,000, which is larger than in Kim *et al*. [12].

When people phonate, the tongue forms the vowel and has a role in forming the resonance cavity. Patients with cerebral infarction have smaller muscle movement ranges in their tongue, lip, and jaw, which are articulators. The musculi larynges are also weakened. In particular, the tongue is an important articulator that is closely involved with the production of sound and the clarity of pronunciation [17, 18]. Regarding our observations of patients with spastic dysarthria due to cerebral infarction, the weakness of pronunciation-related muscles indeed affected pronunciation. We assumed that the differences were revealed because /i/ and /u/ are the vowels pronounced at the upper part of the mouth, which uses less of the tongue muscles compared with /a/ and /æ/, which differed significantly between the mild dysarthria group and the control group.

In this study, we discovered that patients with dysarthria use their tongues in a higher position, putting it further back in the mouth compared to normal adults, because of muscle weakness. This indicates that patients with dysarthria use their resonance cavities less efficiently compared to normal adults. Previous studies had similar results in that formant frequencies of patients with dysarthria showed a significant difference compared to normal adults [1, 19].

Regarding the relationship of F1 and F2 in vowels of normal adults and patients with mild dysarthria, even though the positions of vowels in patients with dysarthria did not exactly match those of normal adults, they had a similar shape. It means that even if patients with dysarthria have limits on their sphere of activity due to the tension of their articulators, they can understand and use the same articulating method and positions of vowels.

Referring to other studies, we generated a rectangular vowel diagram by using the vertex collection of /a/, /i/, /u/, and /æ/. However, we found that both patients with dysarthria and normal adults had a triangular vowel diagram [14, 20]. In other words, Korean vowels were different from English vowels in their positions and auditory effects. These characteristics indicate that Korean vowels are based on the triangular vowel diagram.

The vowel space area of patients with dysarthria was statistically and significantly narrower than that of normal adults. This result was similar to previous research in which the vowel space area of patients with spastic dysarthria was significantly smaller in both the isolated and in context environments [12]. The reason for the significant difference in vowel space area is that the coordinates of vowel space area are widespread to the bottom of the left side due to the locations of vowel /a/ and /æ/. Through this, we can see that compared to normal adults, patients with mild dysarthria show difficulties in using the articulator widely and smoothly. In addition, those patients' tongues, which play an important role in articulation, are centralized due to tonicity.

This study suggests that an objective, acoustical analyzing method is preferable to a subjective, auditory perceptual evaluating method, which is most commonly used in clinical tests of the articulation of speech of patients with mild dysarthria. Through analyzing the vowel space area, which is an acoustical assessment method, we could figure out the location and movement range of articulators, which are otherwise hard to find out when using the subjective evaluating method. We could also set an objective standard by expressing the results in numerical values. Through these results, we suggest a direct mediating method to produce a lucid voice by analyzing the producing pattern of the voices of normal adults and patients with spastic dysarthria based on the objective evaluating standard. We also verified quantitatively that patients with dysarthria use a smaller area of vowel space than normal adults do. This result could be used to evaluate and monitor the clarity of articulation over time of patients with mild dysarthria.

Dysarthria after cerebral infarction can occur with infarctions at various regions of the brain, but this research did not cover the differences among regions. Therefore, future research on sound analysis depending on the regions and types of dysarthria is needed. Also, as this study investigated the formant characteristics of vowels, additional research is needed on the various linguistic units that we commonly use in our daily lives.

Table 1: The comparison of F_1 and F_2 of patients with dysarthria and normal adults

			Mean	SD	t
/a/	F_1	dysarthria	733.7	126.2	-2.432*
		normal	831.1	136.1	
	F_2	dysarthria	1260.1	162.1	-1.555
		normal	1397.1	371.2	
/i/	F_1	dysarthria	355.1	62.9	1.46
		normal	326.9	63.4	
	F_2	dysarthria	2168.4	206.1	-1.947
		normal	2339.9	349.7	
/u/	F_1	dysarthria	400.6	88.0	0.401
		normal	391.3	62.1	
	F_2	dysarthria	878.5	176.7	-.719
		normal	910.2	104.1	
/æ/	F_1	dysarthria	550.3	99.3	1.926
		normal	499.4	72.3	
	F_2	dysarthria	1800.4	182.0	-3.954*
		normal	2079.7	270.4	

* SD: Standard deviation

* $p<0.05$

Table 2: Vowel space area among patients with dysarthria compared with normal adults).

	Mean	SD	t
dysarthria	240775.3	109482	-3.02*
normal	318258.7	112574.2	

* SD: Standard deviation
* $p<0.05$

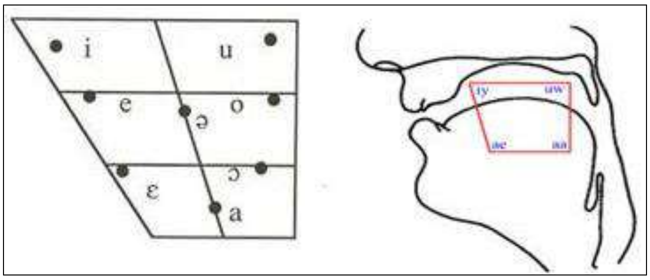

Fig 1: The general vowel space area of normal adults in English-speaking countries.

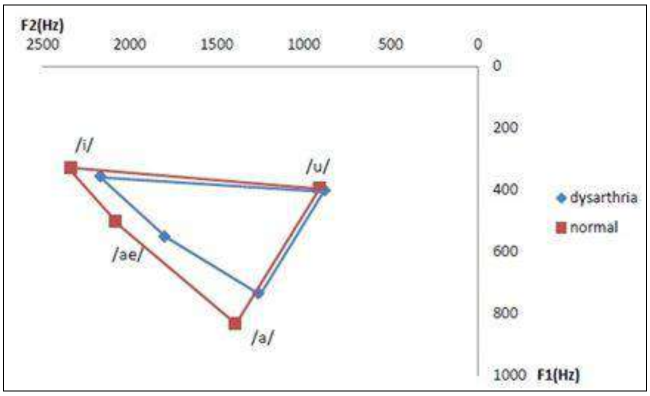

Fig 2: A schematic diagram of patients with dysarthria compared with normal adults.

Conclusion

Even though patients with mild dysarthria do not show great difficulties at the level of a word or a phoneme, their articulation of speech noticeably decreases over a long conversation. This is because these patients use their resonance cavities less efficiently than normal adults, which interferes with articulation. A therapeutic mediation that focuses on the extension of the resonance cavity or a voice producing method could be recommended as an effective treatment.

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