

## Comparison of Acoustic Properties of Fricative Sounds in Individuals with Class I and Class II Skeletal Closure Pattern

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### Abstract

**Objective:** The aim of this study was to analyse the acoustic properties of Turkish fricative sounds (/s, z, ʃ, ʒ, f, v/) produced by individuals with class I skeletal closure pattern and individuals with class II skeletal closure pattern and crowded teeth.

**Materials and Method:** The study was conducted with 4 participants (2 females and 2 males) with class I closure pattern and 4 participants (2 females and 2 males) with class II closure pattern. The words used for data collection in the study were selected from words in which the fricative sounds in Turkish (/s, z, ʃ, ʒ, f, v/) were in word-initial position. The words containing the target sounds were placed in the carrier sentence "Ada said ....." and a list of 18 words was prepared. Five different reading lists were created by changing the order of the words in the list. In the implementation phase, firstly, a consent form was filled out for each participant and confirmation was obtained from the orthodontist about the jaw closure pattern. The application was carried out with the participants who met the inclusion criteria and they were asked to read the word lists containing the target sounds. Participants were instructed to read each sentence clearly and comprehensibly; re-recordings were taken for incomprehensible readings. The reading of the lists was carried out in a noiseless environment where the researcher and the participant were present. During the reading, a RODE microphone voice recorder was used and the recorder was kept at a distance of 10 cm from the participant's mouth. After the lists were read and the recordings were taken, the data were transferred to the PRAAT program and the centre of gravity, duration, skewness and kurtosis values of each sound were determined.

**Results and Conclusion:** The fact that there was no significant difference between the acoustic properties of fricative sounds in individuals with Class I and Class II skeletal closure was interpreted as the difference in skeletal closure pattern in these two groups did not lead to a significant difference in acoustic properties.

In people with Class I and Class II closure patterns, the centre of gravity, skewness and kurtosis values of fricative sounds change as the place of articulation changes. This may be related to changes in the position of the articulatory organs during the production of these speech sounds.

A significant difference was found in the centre of gravity values of /s/, /ʒ/ and /f/ produced by people with class I and class II bite patterns. This finding was interpreted as the fact that people with class II bite pattern did not

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produce the related sounds in the position they should be, and this was caused by the crowding in their tooth alignment.

There was a significant difference in the centre of gravity and duration of fricative sounds in male and female participants regardless of the closure pattern, but no difference was found in kurtosis and skewness values.

**Keywords:** Occlusion, malocclusion, class II closure, crowding, frictional sounds, acoustic analysis

## Introduction

Speech is the meaningful sounds that are formed as a result of the coordinated movements of the lips, teeth, tongue, palatum, velum and mandible, which are the articulatory organs of the lips, teeth, tongue, palatum, velum and mandible, which gain resonance characteristics in various cavities and become phonated by the vibration of the vocal cords of the air that fills the lungs with inspiration (1). Speech intelligibility refers to the degree to which the speech sounds produced by the speaker are understood by the listeners who speak the same native language depending on the way they are vocalised and extracted (2). Speech intelligibility has a very important place in the communication process. There are various factors affecting the intelligibility of speech. In particular, the anatomical structure, function and function of the tongue, teeth, lips and jaw articulators, which play a major role in speech, greatly affect speech intelligibility. Jaw closure pattern, crowding in the arrangement of teeth are among the factors affecting speech intelligibility (3). While the teeth support the language during the production of many speech sounds, they also affect the correct production of sounds and speech intelligibility processes (4).

The dentition consists of two dental arches, the mandibular dental arch and the maxillary dental arch. The central incisors, lateral incisors, canines, premolars and molars are arranged in a dental arch, starting from the midline and moving distally. All the teeth on the right and left sides are symmetrically matched to their corresponding teeth. Labiodental and dental speech sounds such as /f, v, θ, ð/ are among the sounds that teeth are involved in the production process. Orthodontics is the field specialised by dentists who examine the relations of teeth, dental curves, jaws and facial bones with each other, taking into account the age, growth and developmental status of the individual, diagnose and control the harmonious relations of incompatible and crowded teeth, and try to prevent this situation. The term occlusion refers to the closure of the opposing teeth; the relationship that occurs as the maxillary and mandibular teeth approach each other. In order to speak well and make sounds correctly, it is necessary to have a regular tooth-jaw relationship.

In the 1930s, Angle, who defended the basis of orthodontics as occlusion, defined occlusion as "The relationship of the oblique faces of the teeth when they are closed" and made the classification known by his name. This dental classification was made in the sagittal direction and the upper 1st molars were considered fixed and named as "Class I, Class II, Class III" (5).

The way in which the mandibular and maxillary dental arches close or fit together is referred to by the term "occlusion". Class I occlusion is also called normal occlusion; in normal occlusion, the maxillary dental arch partially overlaps the mandibular dental arch; the upper incisor teeth

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are approximately 2 mm in front of the lower incisor teeth. On the other hand, in class II malocclusion, the maxillary dental arch is more anterior than the mandibular dental arch. In class III malocclusion, the mandibular dental arch is more anterior than the maxillary dental arch (4).

Malocclusion is defined as "bad bite" in the literature. It causes the existence of conditions that change the facial features of the individual, prevent a healthy closure due to the structure of the teeth, and cause loss of self-confidence, especially during speech and laughter. Some children's jaws and teeth cannot develop properly. This causes a relationship that is not properly aligned and not in good harmony with the teeth in the opposite jaw. Malocclusion is typically not classified as a disease and does not directly impact overall health. However, severe cases of malocclusion can interfere with essential functions such as eating and speaking, and can also pose challenges in maintaining proper oral hygiene. Factors such as abnormal jaw closure pattern, crowding of teeth, extraction braces treatment will affect and differentiate the shaping of sounds in the oral cavity. Malocclusion can be seen in different ways in individuals. Crowding, impacted teeth, deep bite, open bite, cross bite are among the examples of malocclusion (6). In cases where the patient's jaw is narrow and there is not enough space for the teeth to settle, crowding is seen in the alignment of the teeth, which negatively affects the closing pattern of the lower jaw and upper jaw. In some cases, the orthodontist may have to extract one or more teeth to provide space (5). Crowding is also evident in both class I and class II.

Structural anomalies in the speech production pathway, such as dental or occlusal anomalies, oronasal fistula, or velopharyngeal insufficiency, can lead to obligatory and/or compensatory errors in a child's speech (4). Obligatory pronunciation errors are caused by an abnormality in anatomy or physiology, which results in impaired pronunciation of speech even though the site of pronunciation is normal. These errors are incorrect vocalizations that happen due to abnormal structure and speech physiology. These errors occur when there is a dental or occlusal anomaly, velopharyngeal dysfunction, or fistula. In such cases, sibilant distortions, which are typically associated with malocclusions of Class II and Class III, are observed. (4). Warren (1986) explained that producing the speech sound further back in the mouth and lateralisation occurs in response to the physiological need to maintain aerodynamic stability of compensatory articulation errors in speech due to malocclusion. Articulation in the oral cavity occurs when dental and alveolar pressurised consonants are voiced from the palatal, velar or uvular region. Class II malocclusion can result in the production of speech sounds posterior to their normal position. Lateralisation occurs when the airflow is directed to one or both sides of the oral cavity and the tongue obstructs the midway. For example, /s/ and /ʃ/ may be articulated as [ɬ]. Palatalisation is when the tongue touches the back of the hard palate and the dorsum of the tongue is used instead of the tip of the tongue. For example, the sound /d/ may be articulated as [dʲ], and /ʃ/ as [ç]. Crossbite, excess and abnormally placed teeth are among the factors contributing to lateralisation or palatalisation (4). In people with Class II bite pattern, the maxillary dental arch is more anterior than the mandibular dental arch. In the crowded tooth alignment, the jaw is narrow and the tooth placement area is insufficient. This anatomical difference may adversely affect the provision of the necessary conditions for the production of fricative sounds.

In order to have an airflow that will create turbulence during typical speech, speakers bring their

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articulatory organs closer to each other and create enough air pressure to create friction or explosion immediately after this convergence (8). Fricative sounds are produced by the turbulence caused by this air pressure as it passes through a narrow gap. According to Kent and Shriberg (2002), fricative sounds are the sounds created in the narrow space through which the air passes with a sustained noise. The intensity of this noise varies according to the place of articulation. Alveolar fricatives "/s, z/" are the sounds with the highest noise intensity. Fricatives are not only differentiated by the place of articulation, but also by the size and shape of the groove. For example, the groove for /s/ is much smaller than for /ʃ/ (9).

The difference in the mean distribution in the spectrum may be caused by the place of articulation of the fricative sound. During the formation of the fricative sound, the increase in the length of the anterior cavity or the length of the constriction causes the centre of gravity, which is the first spectral moment, to decrease, while the centre of gravity of the fricative sound increases to higher frequencies with the shortening of the oral cavity in front of the constriction (10).

The time between the start and end point of the fricative sound is the noise duration. What distinguishes fricative sounds from other sound groups is the length of their aperiodic energy intervals (11).

The kurtosis value of fricative sounds is a crucial parameter for analyzing and comprehending speech production and it offers insights into the level of concentration or dispersion of energy in the frequency spectrum. A greater kurtosis value signifies a distribution of energy that is more focused, with more distinct peaks and a narrower range of frequencies. This can suggest a more concentrated and clearly defined fricative sound. Conversely, a lower kurtosis value indicates a more dispersed distribution of energy, characterized by less pronounced peaks and a wider span of frequencies. This could lead to a less distinct and discernible fricative sound. According to Forrest et al. (1998), kurtosis is the most important variable that distinguishes /s/ from /ʃ/ among sibilant features. Fox and Nissen (2005) found that /s/ has a higher kurtosis value than /ʃ/.

The concept of skewness expresses the skewness of the distribution. In the phonetic sense, skewness refers to the spectral skewness, i.e. the average skewness of the energy distribution and indicates the asymmetry of the distribution. Zero skewness shows three types of skewness as a balanced and symmetrical distribution around the centre of gravity. A positive skewness can be mentioned when the distribution is not balanced, where the right end of the distribution extends further than the left end. In the other case, where the left end of the distribution extends further than the right end, the skewness is negative.

There are many studies on the acoustic values of fricative sounds in healthy subjects (12, 13,14,15). These studies show that the most detailed information about fricative sounds is provided by these 4 spectral moment parameters by measuring the centre of gravity, variance, skewness and kurtosis (16).

The centre of gravity for fricatives is an important acoustic measure that helps to analyse and distinguish between different fricative consonants. It provides information about the distribution of energy in different frequency bands and can be used to characterise fricative sounds according to their spectral properties. Understanding the centre of gravity of fricative sounds is very

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important to study their acoustic properties and to distinguish between different fricative consonants. The centre of gravity of the sound increases as the constriction of the anterior part of the oral cavity increases during sound production. Accordingly, the centre of gravity value of /s/, which is a postdental sound, is higher than /ʃ/, which is a postdental-palatal sound (10,17).

The skewness of fricative sounds refers to the asymmetry in their energy distribution, especially in terms of intensity and frequency. It indicates whether the distribution is more concentrated at the upper or lower end of the spectrum; positive skewness indicates a longer tail towards higher values, while negative skewness indicates a longer tail towards lower values. The skewness of fricative sounds can provide information about their acoustic properties and perceptual differences between different types of friction. Many studies in the literature show that the skewness value in fricative sounds is affected by the location of the place where the sound is produced in the oral cavity (10). In some studies, it has been found that the skewness value increases as the place of articulation goes further back (14,15,16,), while in others, the skewness value of the /s/ sound with a more prominent articulation place was found to be higher than the /ʃ/ sound articulated further back (10).

Looking at the studies in Turkish, it is seen that the acoustic properties of fricative sounds were determined in the study conducted by Ertan (2011) and the acoustic properties of fricative sounds in children with cleft lip and palate with hypernasality were examined in the study conducted by Balo (2016). However, no study was found in the literature on the effect of variables such as closure pattern and crowding of teeth on the acoustic properties of fricative sounds in Turkish.

There are various programmes used for acoustic analysis of speech sounds; PRAAT is one of them. In one of the various studies conducted in Turkish using PRAAT, Kılıç (2012) determined the voice onset time (VOT) of explosive stop sounds with the PRAAT programme. The PRAAT programme was also used to analyse the speech sounds of hearing impaired children (18) and children with cleft lip and palate (10,19). Balo (2016) acoustically analysed the fricative sounds of children with cleft lip and palate with hypernasality and found that hypernasality in these children affected the duration, centre of gravity and kurtosis values of fricative sounds.

The objective of this study was to examine the acoustic characteristics of Turkish fricative sounds (/s, z, ʃ, ʒ, f, v/) produced by individuals with a class I skeletal closure pattern and individuals with a class II skeletal closure pattern characterized by crowded teeth.

When the studies in the literature are examined, it is seen that studies based on acoustic analysis of speech sounds were conducted with healthy individuals, hearing impaired children and children with cleft lip and palate. There is no study on the acoustic properties of fricative sounds in occlusal anomalies and how these properties differ from normal. This study is important in terms of being the first in this respect.

## **Purpose**

In this study, it was aimed to analyse the acoustic properties of Turkish fricative sounds (/s, z, ʃ, ʒ, f, v/) produced by individuals with class I skeletal closure pattern and individuals with class II skeletal closure pattern with crowded teeth. Within the scope of the aim of the study, answers to the following questions were sought:

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- 1- What are the kurtosis, centre of gravity, skewness values and duration of the fricative sounds produced by individuals with Class I closure pattern?
- 2- What are the kurtosis, centre of gravity, skewness values and duration of the frictional sounds produced by individuals with Class II bite pattern and crowding in tooth alignment?
- 3- Is there a difference between the kurtosis, centre of gravity, skewness values and duration of fricative sounds produced by people with Class I and Class II closure pattern?
- 4- Does the place of articulation affect the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with Class I closure pattern?
- 5- Does the place of articulation affect the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with crowded teeth with Class II bite pattern?
- 6- Does voicing/devoicing affect the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with Class I closure pattern?
- 7- Do the duration, centre of gravity, skewness and kurtosis values of fricative sounds affected by voicing/devoicing in people with crowded teeth with Class II bite pattern?
- 8- Does gender affect the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with Class I and Class II bite patterns with crowded teeth?

## **Method**

In this study, acoustic properties such as centre of gravity, duration, skewness and kurtosis values of fricative sounds produced by individuals with class I bite pattern and individuals with class II bite pattern with crowded teeth were analysed descriptively and comparatively.

## **Participants**

This study was conducted with 8 participants. Four of the participants were individuals with class I closure pattern and the other four were individuals with class II closure pattern. The participants were evenly distributed in terms of gender, with an equal number of males and females. Our research was conducted with 2 female participants aged 24, 25 years and 2 male participants aged 25, 27 years with class I closure pattern; 2 female participants aged 18, 23 years and 2 male participants aged 26, 28 years with class II closure pattern. It was ensured that the age of the participants was 15 and above. The reason why 15 years of age is the limit is that the jaw development is completed by this age.

Before the study, the participants were informed and their consent was obtained. While determining the occlusion pattern of the participants, information was obtained from the orthodontist. Groups were formed according to the classification made by the expert. The inclusion and exclusion criteria of the study are given below.

The inclusion criteria are: Being 15 years of age or older, native language being Turkish, having a class I bite pattern (Group 1), individuals in the control group having normal dental anatomy, having a class II bite pattern with dental crowding (Group 2), individuals not having hearing

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 difficulties, neurological disorders, language and speech disorders.

The exclusion criteria are as follows: Non-Turkish mother tongue, age below 15 years, class I or class II bite pattern, class II bite pattern but no crowding in tooth alignment.

The study was conducted in various orthodontic clinics with individuals who met the inclusion criteria of the study. Dependent variables were acoustic characteristics of frictional sounds such as centre of gravity, inclination, kurtosis and duration. Independent variables were tooth alignment and Class II bite pattern.

### Material

The words used for data collection in the study were selected from words in which the fricative sounds in Turkish (/s, z, ʃ, ʒ, f, v/) were in word-initial position. The first, second and third authors decided on the words together. The vowel /a/ was placed after the target sound in the words for easy and clear analysis. In order to keep the phonological context constant and to prevent possible acoustic changes, it was ensured that the word preceding the target sound ended with an /a/ vowel and the sound following it was an /a/ vowel. The words containing the target sounds were placed in the carrier sentence "Ada said ....." and 5 lists of 18 words each were prepared.

### Data collection

Participants who met the inclusion criteria were asked to read word lists containing target sounds. The participants were instructed to read each sentence clearly and comprehensibly. The reading of the lists was carried out in a noiseless environment where the researchers and the participant were present. During the reading, Rode NT1 5th a voice recorder was used and the recorder was kept at a distance of 10 cm from the participant's mouth. After the lists were read and the recordings were taken, the data were transferred to the PRAAT program and the centre of gravity, duration, skewness and kurtosis values of each sound were determined.

### Results

The kurtosis, centre of gravity, skewness and duration values of the fricative sounds produced by individuals with class I and class II closure patterns were compared by Student's t test; the results are shown in Table 1.

**Table 1.** Characteristics of fricative sounds in class I and class II closure pattern

|          | Group    | Average | SD     | t     | p     |
|----------|----------|---------|--------|-------|-------|
| Cog      | Class I  | 4455    | 3525   | 1.138 | 0.255 |
|          | Class II | 4150    | 3661   |       |       |
| Skewness | Class I  | 5.73    | 14.76  | 0.205 | 0.838 |
|          | Class II | 5.52    | 12.16  |       |       |
|          | Class I  | 433.7   | 1784.6 | 1.812 | 0.07  |

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|          |          |       |       |        |       |
|----------|----------|-------|-------|--------|-------|
| Kurtosis | Class II | 245.3 | 841.3 |        | 0     |
| Duration | Class I  | 116.5 | 37.24 | -1.423 | 0.155 |
|          | Class II | 120.7 | 40.65 |        |       |

When Table 1 is examined, it is seen that the mean for the kurtosis value of fricative sounds is 433.7 (sd=1784.6), the mean for the centre of gravity is 4455 (sd=3525), the mean for the skewness value is 5.73 (sd=14.76) and the mean duration is 116.56 (sd= 37.24) for individuals with class I closure pattern. In people with Class II closure pattern, the mean for the kurtosis value of fricative sounds was 245.3 (sd= 841.3), for the centre of gravity 4150 (sd= 3661), for the skewness value 5.52, (sd= 12.16) and for the duration 120.7 (sd= 40.65). Student's t test was applied to determine whether there was a significant difference between the kurtosis, centre of gravity, skewness values and duration of the fricative sounds produced by people with Class I and Class II closure patterns. According to the results of Student's t test, it was determined that there was no significant difference between the centre of gravity (t=1.138, p=0.255), skewness (t=0.205, p=0.838), kurtosis (t=1.812, p=0.070) and duration (t=-1.423, p=0.155) characteristics of both groups (p>0.05).

In order to find an answer to the question whether the place of articulation affects the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with Class I closure pattern, centre of gravity, kurtosis, skewness and duration values were analysed with three group ANOVA test. Fricative sounds were divided into three groups as labio-dental (Group 1: /f-v/), alveolar (Group 2: /s-z/) and postalveolar (Group 3: /ʃ-ʒ/) sounds according to the place of articulation and it was examined whether there was a difference between these groups. The results are shown in Table 2.

**Table 2.** Duration, centre of gravity, skewness and kurtosis values for Class I closure pattern according to place of articulation

|          |         | Mean  | SD    | ANOVA  |        | Bonferroni Test |        |
|----------|---------|-------|-------|--------|--------|-----------------|--------|
|          |         |       |       | F      | p      | Group           | p      |
| Cog      | Group1  | 7127  | 2629  | 73.535 | <0.001 | 1-2             | <0.001 |
|          | Group 2 | 3375  | 1014  |        |        | 1-3             | <0.001 |
|          | Group 3 | 2862  | 952.3 |        |        | 2-3             | <0.001 |
| Kurtosis | Group1  | 256.5 | 83.0  | 8.295  | <0.001 | 1-2             | <0.001 |
|          | Group 2 | 88.8  | 29.6  |        |        | 1-3             | <0.001 |
|          | Group 3 | 955.9 | 169.6 |        |        | 2-3             | <0.001 |
| Skewness | Group1  | 3.9   | 1.0   | 20.753 | <0.001 | 1-2             | <0.001 |
|          | Group 2 | 4.8   | 1.6   |        |        | 1-3             | <0.001 |

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|          |         |       |      |       |       |     |        |
|----------|---------|-------|------|-------|-------|-----|--------|
|          | Group 3 | 12.4  | 4.0  |       |       | 2-3 | <0.001 |
| Duration | Group1  | 118.2 | 30.6 | 3.092 | 0.047 | 1-2 | 0.990  |
|          | Group 2 | 121.5 | 30.9 |       |       | 1-3 | 0.252  |
|          | Group 3 | 110.0 | 47.1 |       |       | 2-3 | 0.049  |

When Table 2 is examined, it is found that the centre of gravity, kurtosis, skewness and duration values of fricative sounds change as the place of articulation changes in the group with class I closure pattern. For example, while the centre of gravity is highest for /f-v/ produced from the front of the mouth (mean= 7127; SD=2629), it decreases as one moves towards the back of the oral cavity (mean=3375, SD=1014) for /s-z/; mean=2862, SD=952.3 for /ʃ-ʒ/. The kurtosis value was found to be the highest for /ʃ-ʒ/, which is the postalveolar sound, and the lowest for /s-z/, which is the alveolar sound. While the skewness value was highest for /ʃ-ʒ/, which is a postalveolar sound and produced in the more posterior part of the mouth, it decreased as one moves towards the front of the oral cavity (mean=12.4, SD=4.0 for /s-z/, mean=4.8, SD=1.6 for /f-v/). When Table 2 is examined, a significant difference was found between the groups according to place of articulation for the variables of centre of gravity, kurtosis, skewness and duration ( $p < 0.001$ ). Bonferroni test, one of the Post-Hoc tests, was performed after the ANOVA test to find out which group was different. Significant differences in the centre of gravity, kurtosis, and skewness values were observed in pairwise comparisons when the articulation place of the fricative sounds changed ( $p < 0.001$ ). The duration values of the fricative sounds were found to be very close to each other and the difference between them was not significant ( $p > 0.001$ ).

In order to examine the duration, centre of gravity, skewness and kurtosis values of fricatives according to the place of articulation in people with Class II closure pattern, fricatives were divided into three groups as labio-dental (Group 1: /f-v/), alveolar (Group 2: /s-z/) and postalveolar (Group 3: /ʃ-ʒ/) sounds according to the place of articulation. The results are shown in Table 3.

**Table 3.** Duration, centre of gravity, skewness and kurtosis values of Class II closure pattern according to place of articulation

|          |        | Mean | SD    | ANOVA |        | Bonferroni Test |        |
|----------|--------|------|-------|-------|--------|-----------------|--------|
|          |        |      |       | F     | p.     | Group           | p      |
| Cog      | Group1 | 7181 | 1832  | 131.7 | <0.001 | 1-2             | <0.001 |
|          | Group2 | 3960 | 644.5 |       |        | 1-3             | <0.001 |
|          | Group3 | 1363 | 486.9 |       |        | 2-3             | <0.001 |
| Skewness | Group1 | 3.2  | 1.7   | 75.48 | <0.001 | 1-2             | <0.001 |
|          | Group2 | 4.6  | 1.3   |       |        | 1-3             | <0.001 |
|          | Group3 | 14.8 | 5.2   |       |        | 2-3             | <0.001 |
|          | Group1 | 18.8 | 3.1   | 31.7  | <0.001 | 1-2             | <0.001 |

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|          |        |       |       |           |       |     |        |
|----------|--------|-------|-------|-----------|-------|-----|--------|
| Kurtosis | Group2 | 10.2  | 3.4   | 5         |       | 1-3 | <0.001 |
|          | Group3 | 707.0 | 145.1 |           |       | 2-3 | <0.001 |
| Duration | Group1 | 123.3 | 43.2  | 1.53<br>2 | 0.217 | -   | -      |
|          | Group2 | 123.4 | 38.6  |           |       | -   | -      |
|          | Group3 | 115.4 | 39.8  |           |       | -   | -      |

When Table 3 is analysed, it is seen that the acoustic values of fricative sounds in subjects with class II closure pattern are similar to those with class I closure pattern. For example, the centre of gravity values were found to be the highest for /f-v/ sounds, which are labio-dental sounds and produced from the most anterior point of the mouth (mean= 7182; SD=1832), and the lowest for /ʃ-z/ sounds, which are postalveolar sounds and produced in a more posterior position in the oral cavity (mean=1363, SD=486.9). The kurtosis value was highest for /ʃ-z/ (mean=707.0, SD=145.1) and lowest for /s-z/ (mean=10.2, SD=3.4). The skewness value was highest for /ʃ-z/, which is an interdental palatal sound and produced in the more posterior part of the mouth (mean=14.8, SD=5.2), and decreased as one moves towards the front of the oral cavity (mean=4.6, SD=1.3 for /s-z/, mean=3.2, SD=1.7 for /f-v/). In the group with Class II closure pattern, a significant difference was observed between the centre of gravity, kurtosis and skewness values of the fricatives with different articulation locations ( $p < 0.001$ ). However, it was discovered that there was no statistically significant difference in the duration variable within this group, despite the change in articulation place of the sounds ( $p > 0.05$ ).

The t-test was applied to determine whether the centre of gravity, skewness, kurtosis and duration values for each fricative sound differed between the groups in individuals with class I and class II closure patterns; the results are shown in Table 4. When Table 4 is examined, it is seen that there is a significant difference between the centre of gravity values of the /s/ sound in people with class I and class II closure patterns (mean= 9175, SD= 1612 for class I; mean= 10067, SD= 810.1 for class II) ( $p < 0.001$ ). A similar finding was found for the centre of gravity value of the /ʒ/ sound (mean= 2955, SD= 2251 for class I; mean= 1858, SD= 1532 for class II) ( $p < 0.001$ ). No significant difference was found between the groups for the skewness, kurtosis and duration values of these two sounds ( $p > 0.05$ ). When the acoustic properties of /z/, /ʃ/ and /v/ were compared in subjects with class I and class II closure patterns, no significant difference was found between the centre of gravity, pitch, kurtosis and duration values ( $p > 0.05$ ). A significant difference was found between the centre of gravity (mean=2460, SD=2506 for class I; mean=5460, SD=2249 for class II) and skewness values (mean=5,658, SD=10,08 for class I; mean= 0,624, SD=2,253 for class II) of the /f/ sound ( $p < 0.001$ ;  $p < 0.05$ ), while no significant difference was found between kurtosis and duration values ( $p > 0.05$ ).

**Table 4.** Acoustic values of frictional sounds in class I and class II

|                            | Paired ... | t      | p     |                              |
|----------------------------|------------|--------|-------|------------------------------|
|                            |            |        |       | 95% CI (Confidence Interval) |
|                            |            |        |       | Upper                        |
| /s/ Cog Class I - Class II | -495.0     | -4.498 | <0.00 |                              |

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|                                 |        |        |        |
|---------------------------------|--------|--------|--------|
|                                 |        |        | 1      |
| /s/ Skew Class I - Class II     | 0.731  | 0.731  | 0.468  |
| /s/ Kurtosis Class I - Class II | 17.64  | 0.824  | 0.413  |
| /s/ Duration Class I - Class II | 27.28  | 2.746  | 0.008  |
| /z/ Cog Class I - Class II      | 2338   | 1.492  | 0.141  |
| /z/ Skew Class I - Class II     | 0.851  | -1.630 | 0.108  |
| /z/ Kurtosis Class I - Class II | 131.5  | -1.571 | 0.122  |
| /z/ Duration Class I - Class II | 3.154  | -1.279 | 0.206  |
| /ʃ/ Cog Class I - Class II      | 295.5  | 0.666  | 0.508  |
| /ʃ/ Skew Class I - Class II     | 0.030  | -10.71 | 0.092  |
| /ʃ/ Kurtosis Class I - Class II | 0.980  | 0.148  | 0.883  |
| /ʃ/ Duration Class I - Class II | 170.0  | 10.82  | 0.073  |
| /ʒ/ Cog Class I - Class II      | 16780  | 30.76  | 0.000  |
| /ʒ/ Skew Class I - Class II     | 0.315  | -10.76 | 0.083  |
| /ʒ/ Kurtosis Class I - Class II | 240.7  | -10.73 | 0.089  |
| /ʒ/ Duration Class I - Class II | 50.26  | -0.913 | 0.365  |
| /f/ Cog Class I - Class II      | -1935  | -50.64 | <0.001 |
| /f/ Skew Class I - Class II     | 70.80  | 30.64  | 0.001  |
| /f/ Kurtosis Class I - Class II | 2780   | 10.80  | 0.077  |
| /f/ Duration Class I - Class II | 190.7  | 20.05  | 0.045  |
| /v/ Cog Class I - Class II      | 670.2  | 0.095  | 0.925  |
| /v/ Skew Class I - Class II     | 70.24  | -0.057 | 0.955  |
| /v/ Kurtosis Class I - Class II | 3120   | -10.34 | 0.186  |
| /v/ Duration Class I - Class II | 180.72 | 0.095  | 0.924  |

In order to find an answer to the question "Does voicing/devoicing affect the duration, centre of gravity, skewness and kurtosis values of fricative sounds in people with Class I closure pattern?", an independent sample t test was performed. The results are shown in Table 5.

**Table 5.** Duration, centre of gravity, skewness and kurtosis values for Class I closure pattern according to the voicing/devoicing

| Group Statistics |              |       |       | t     | p      |
|------------------|--------------|-------|-------|-------|--------|
| Group            |              | Mean  | SD    |       |        |
| Cog              | 1- voiced    | 21030 | 14770 | 161.0 | <0.001 |
|                  | 2- voiceless | 68060 | 27680 |       |        |
| Skewness         | 1-voiced     | 110.4 | 80.22 | 70.82 | <0.001 |
|                  | 2- voiceless | 0.100 | 0.04  |       |        |
| Kurtosis         | 1-voiced     | 8630  | 2520  | 40.70 | <0.001 |
|                  | 2- voiceless | 40.31 | 10.03 |       |        |
| Duration         | 1-voiced     | 1050  | 430.1 | 50.75 | <0.001 |
|                  | 2- voiceless | 1270  | 260.2 |       |        |

SD: Standard Deviation

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When Table 5 is examined, a significant difference ( $p < 0.001$ ) was found in terms of centre of gravity ( $t = 161.0$ ,  $p < 0.001$ ), skewness ( $t = 70.82$ ,  $p < 0.001$ ), kurtosis ( $t = 40.70$ ,  $p < 0.001$ ), duration ( $t = 50.75$ ,  $p < 0.001$ ) properties of voicing/devoicing.

When the duration, centre of gravity, skewness and kurtosis values of the voiced and unvoiced fricative sounds were compared in people with crowded teeth with Class II bite pattern, significant difference was found between the groups. Upon examination of Table 6, a statistically significant difference ( $p < 0.001$ ) was observed in the following properties of voicing/devoicing: the centre of gravity ( $t = -70.63$ ,  $p < 0.001$ ), skewness ( $t = 60.12$ ,  $p < 0.001$ ), kurtosis ( $t = 40.52$ ,  $p < 0.001$ ) and duration characteristics ( $t = 70.626$ ,  $p < 0.001$ ).

**Table 6.** Duration, centre of gravity, skewness and kurtosis values according to the crowding in Class II closure pattern

| Group Statistics |             |       |       | t      | p      |
|------------------|-------------|-------|-------|--------|--------|
| Group            |             | Mean  | SD    |        |        |
| Cog              | 1-voiced    | 28030 | 14640 | -70.63 | <0.001 |
|                  | 2-voiceless | 55330 | 13280 |        |        |
| Skewness         | 1-voiced    | 90.26 | 30.01 | 60.12  | <0.001 |
|                  | 2-voiceless | 10.79 | 00.54 |        |        |
| Kurtosis         | 1-voiced    | 4400  | 1100  | 40.52  | <0.001 |
|                  | 2-voiceless | 500.0 | 211.0 |        |        |
| Duration         | 1-voiced    | 1020  | 340.3 | -90.39 | <0.001 |
|                  | 2-voiceless | 1380  | 380.5 |        |        |

The duration, centre of gravity, skewness and kurtosis values of fricative sounds were examined as a whole according to gender in people with Class I and Class II bite patterns with crowded tooth alignment, and a significant difference was found in terms of centre of gravity ( $t = 50.56$ ,  $p < 0.001$ ), duration ( $t = 120.7$ ,  $p < 0.001$ ) of fricative sounds ( $p < 0.001$ ); no significant difference was found in terms of skewness ( $t = 20.58$ ,  $p > 0.05$ ), kurtosis ( $t = 30.36$ ,  $p > 0.05$ ) ( $p > 0.05$ ).

**Table 7.** Acoustic values of fricative sounds according to gender

|          | Gender | Mean  | SD    | t     | p      |
|----------|--------|-------|-------|-------|--------|
| Cog      | Female | 50420 | 28410 | 50.56 | <0.001 |
|          | Male   | 35810 | 8650  | 50.56 | <0.001 |
| Skewness | Female | 60.93 | 20.45 | 20.58 | 0.010  |
|          | Male   | 40.33 | 20.57 | 20.58 | 0.010  |
| Curtosis | Female | 5130  | 1330  | 30.36 | 0.001  |
|          | Male   | 1650  | 690.4 | 30.36 | 0.001  |

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|          |        |      |       |        |        |
|----------|--------|------|-------|--------|--------|
| Duration | Female | 1350 | 380.9 | 120.70 | <0.001 |
|          | Male   | 1010 | 310.1 | 120.70 | <0.001 |

## Discussion

In this study, acoustic properties such as centre of gravity, duration, pitch and kurtosis values of fricative sounds (/s, z, ʃ, ʒ, f, v/) in Turkish produced by participants with class I skeletal closure pattern and individuals with class II skeletal closure pattern with crowded teeth were compared.

Although the centre of gravity, kurtosis, skewness and duration values of fricative sounds were found to be lower in group with class II closure pattern than those with class I closure pattern, no significant difference was found between the groups. This was interpreted as the difference in skeletal closure pattern in the two groups did not lead to a significant difference in the acoustic properties of fricative sounds. In a similar study conducted with children with cleft lip and palate with hypernasality, different findings were obtained and it was reported that hypernasality affected the duration, centre of gravity and kurtosis values of fricative sounds (10). In this study, it was found that skeletal closure pattern did not affect the centre of gravity, skewness, kurtosis and duration values of fricative sounds. In cleft lip and palate cases, individuals have difficulty in creating intraoral pressure due to cleft lip and/or palate, and they tend to produce speech sounds in the more posterior part of the mouth rather than in the position they should be (10). This affects the centre of gravity, duration, skewness and kurtosis values of fricative sounds. The findings of this study showed that having a class II bite pattern and crowding did not have a significant effect on the related values of fricative sounds.

In both class I and class II closure patterns, the centre of gravity of fricative sounds was found to be the highest for /f-v/ sounds, which are labio-dental sounds and produced at the very front of the oral apparatus, and the lowest for /ʃ-ʒ/ sounds, which are postalveolar sounds and produced more posteriorly in the oral cavity. The skewness value was found to be the highest for /ʃ-ʒ/ sounds and the lowest for /f-v/ sounds in both groups. The kurtosis value was ranked as /ʃ-ʒ/ > /f-v/ > /s-z/ in both groups. These findings show that the centre of gravity, skewness and kurtosis parameters of the fricative sounds in both closure patterns are in a similar distribution, although they take different values from each other. The study revealed that the skeletal closure pattern didn't have a significant impact on the center of gravity, skewness, kurtosis, and duration of fricative sounds. Individuals with cleft lip and palate experience challenges in generating intraoral pressure as a result of the cleft lip and/or palate. Consequently, they tend to articulate speech sounds towards the back of the mouth instead of their intended position. These fricative sounds are impacted in terms of their center of gravity, duration, skewness, and kurtosis values. The results of this study indicated that the presence of a class II bite pattern with crowding did

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not exert a substantial impact on the associated measurements of fricative sounds.

It was found that the centre of gravity, kurtosis, skewness and duration values of fricative sounds changed as the place of articulation changed in both groups. It was found that the value of the centre of gravity was highest for /f-v/ sounds produced from the front of the mouth in both Class I and Class II closure pattern groups, while it decreased as one moves towards the back of the oral cavity. This finding coincides with other studies in the literature (10,17). In both groups, it was found that the skewness values were the highest for the postalveolar sounds and the lowest for the labio-dental sounds with the production site located further back in the oral cavity. This discovery aligns with previous studies that indicate an increase in skewness value as the articulation point moves further back (15,16). The center of gravity and skewness values of fricative sounds in individuals with a class I closure pattern yield comparable results to those reported in studies on the overall acoustic characteristics of fricative sounds in existing literature. While individuals with a class II closure pattern exhibited distinct variations in their centre of gravity and skewness values compared to those with a class I pattern, it is important to note that these differences did not reach statistical significance. Consequently, this lack of statistical significance may have contributed to the similar findings observed in the class II group.

In subjects with class I and class II closure patterns, the kurtosis values of fricative sounds were found to be the highest in the postalveolar sounds and the lowest in the alveolar sounds. On the other hand, some studies in the literature state that the kurtosis value is higher for sounds with a more anterior articulation place (13), while others state that this value is higher for sounds with a posterior articulation place (15). The current study found that the kurtosis value of the /ʃ-ʒ/ vowels produced in the posterior part of the oral cavity was the highest. Additionally, the kurtosis value of the /f-v/ vowels produced in the anterior part of the oral cavity was higher than that of the /s-z/ vowels produced in the posterior part of the oral cavity. To comprehend and analyze the ordering of the kurtosis value as alveodental>labiodental>alveolar in both class I and class II groups, further data and individual analyses of each speech sound within each group are deemed necessary.

When it was examined whether the centre of gravity, skewness, kurtosis and duration values for each fricative sound differed between the groups in individuals with class I and class II closure patterns, it was observed that there was a significant difference between the centre of gravity values of the /s/ sound ( $p<0.001$ ). The previous finding of our study is that the centre of gravity varies according to the production location of the sound, and this value increases as the production location of the sounds becomes more prominent, and this finding is in line with other studies in the literature (10,15,16,17). The mean centre of gravity of the /s/ sound was found to be higher in people with class II closure pattern than in people with class I pattern (mean= 91741, SD= 16111 for class I; mean= 100661, SD= 8100 for class II). This finding shows that people with class II closure pattern produce the /s/ sound in a more anterior position. For the posterior palatal sound /ʒ/, the mean centre of gravity of the group with class II closure pattern was lower than the group with class I pattern (mean= 2955, SD= 2251 for class I; mean= 1858, SD= 1532 for class II). This finding can be interpreted as that people with class II closure pattern produce the /ʒ/ sound further back than it should be. The centre of gravity values of /f/ also indicate a significant difference between the groups (mean= 2460, SD= 2506 for class I; mean=

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5460, SD= 2249 for class II). The centre of gravity values of the /f/ sound were found to be higher in those with Class II pattern. This finding indicates that the /f/ sound is produced more frontally just like the /s/ sound.

It was found that the duration, centre of gravity, skewness and kurtosis values of the voiced and unvoiced fricative sounds were different from each other in people with class I and class II closure pattern and the difference was statistically significant. In the study conducted by Jongman et al. (2000), it was found that the voiceless fricatives had higher skewness and kurtosis values than the voiced fricatives. The findings of this study, on the other hand, show that the kurtosis and skewness values of the voiceless fricatives are higher in both groups. On the other hand, in parallel with the studies in the literature (17, 20), which reported that voiced fricative sounds were shorter than voiceless fricatives, a similar finding was found in this study.

When the acoustic values of fricative sounds were examined in terms of gender, it was found that the centre of gravity and duration values of women were higher than men and the difference was significant. Especially the finding related to the centre of gravity variable coincides with the results of studies reporting that gender also affects the centre of gravity value and this value is higher in women (12,15). Gender-related disparities in the acoustic characteristics of fricative sounds, specifically in relation to center of gravity measurements, might exist. This could potentially be linked to gender-based disparities arising from differences in the vocal tract related to biological sex.

## Conclusion

The aim of this study was to compare the acoustic properties such as centre of gravity, duration, skewness and kurtosis values of fricative sounds in Turkish produced by individuals with class I skeletal closure pattern and individuals with class II skeletal closure pattern and crowded teeth. Although the centre of gravity, kurtosis, skewness and duration values of fricative sounds were found to be lower in people with class II bite pattern than those with class I bite pattern, no significant difference was found between the groups.

It was found that the centre of gravity, skewness and kurtosis parameters of the frictional sounds in both class I and class II closure patterns took different values from each other but had a similar distribution.

It was found that there were differences in the centre of gravity values of /s/, /ʒ/ and /f/ between the groups; it was interpreted that people with class II closure pattern produced /s/ and /f/ in a more anterior position and /ʒ/ in a more posterior position.

It was found that the centre of gravity, skewness, kurtosis and duration values of the fricative sounds changed in relation to the singing/non-singing feature of the sounds and the gender of the participants.

## Limitations

Despite the study being conducted with a total of 8 participants, each group consisted of only 4 participants. By ensuring gender parity among the participants, data was collected from an equal

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number of 2 female and 2 male participants in each group. This poses a constraint on the research. We recommend increasing the number of participants in future studies of a similar nature.

The acoustic values of fricative sounds did not exhibit statistically significant differences between the groups in our research. Nevertheless, it is anticipated that individuals with a class II bite pattern and dental crowding will have speech intelligibility that differs from those with a class I pattern. Given the circumstances, we propose that future studies should incorporate assessments that measure the speech intelligibility.

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