

تأثير اضطراب الفك السفلي في إنتاج الأصوات الساكنة الهشة لدى الأطفال

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عثمان ، دلخشان يوسف ، تأثير اضطراب الفك السفلي في إنتاج الأصوات الساكنة الهشة لدى  
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## aThe Effect of Mandibular Disorder on the Production of Vulnerable Consonant Sounds in Children

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#### المستخلص

تبحث هذه الدراسة الاستكشافية، بوصفها دراسة حالة، في العلاقة بين اضطراب الفك السفلي، الذي يُعرّف بأنه حركة غير منتظمة للفك السفلي، والإنتاج الصوتي للأصوات الساكنة الهشّة (/s/ ، /z/ ، /ʒ/ ، /dʒ/ ، /g/ ، /d/ ، /l/ ، و /n/) وقد اختيرت هذه الأصوات الساكنة على أساس أن إنتاجها يعتمد بدرجة كبيرة على تشكيل التجويف الفموي ووضع اللسان؛ إذ يُفترض أن الحركة المفرطة أو غير المتساوية للفك السفلي قد تؤدي إلى اضطراب إنتاجها بصورة دقيقة. اختير أحد عشر طفلاً ناطقاً باللغة الكردية، تتراوح أعمارهم بين 10 و 13 سنة، بصورة قصدية للمشاركة في الدراسة. وقد شُخص جميع المشاركون من قبل اختصاصي في تقويم الأسنان بأن لديهم حركات غير مستقرة للفك السفلي، وقُسموا إلى مجموعتين فرعيتين: ستة مشاركين لديهم انحراف في الفك السفلي، وخمسة لديهم انحراف مساري/انحراف أثناء الحركة (deflection). جُمعت البيانات من خلال تسجيل أصوات الأطفال أثناء إنتاجهم للأصوات

المفردة والمقاطع القصيرة التي تحتوي على الأصوات المستهدفة. وبعد ذلك، حُلَّت التسجيلات تحليلًا صوتيًا باستخدام برنامج Praat لتحليل الأصوات.

تشير النتائج إلى وجود علاقة واضحة بين اضطراب الفك السفلي وعدم الدقة في إنتاج الأصوات الهشّة، ولا سيما فيما يتعلق بخصائص المدة والقمة الطيفية. كما أظهرت النتائج أن تأثير اضطراب الفك السفلي كان أكبر بكثير في الأصوات الاحتكاكية /z/ و /s/ و /3/ مقارنةً بالأصوات المستهدفة الأخرى. وعلى الرغم من أن العلاقة كانت واضحة بين كلتا مجموعتي اضطراب الفك السفلي والإنتاج غير الدقيق للأصوات المستهدفة، فإن الفروق في المتوسطات الكلية للمعلمات الصوتية بين مجموعتي الانحراف (deviation) والانحراف المساري (deflection) لم تصل إلى مستوى الدلالة الإحصائية.

### Abstracts

This exploratory case study examines the association between mandibular disorder, defined as irregular movement of the lower jaw, and the acoustic production of vulnerable consonant sounds (/s/, /z/, /3/, /dʒ/, /g/, /d/, /l/, and /n/). These consonants were selected on the grounds that their production depends highly on oral cavity configuration and tongue positioning; excessive or uneven movement of the mandible is hypothesized to disrupt their accurate articulations. Eleven Kurdish-speaking children aged between 10 and 13 years were purposively selected for inclusion in the study. All participants had been diagnosed with unstable mandibular movements by an orthodontic specialist, and were divided into two subgroups: Six participants presenting with mandibular deviation and five had mandibular deflection. Data were collected via recording the children's voice while producing individual sounds and short syllables containing the target sounds. The recordings were subsequently analyzed acoustically using the Praat sound analysis software programme. Findings indicate a clear association between mandibular disorder and inaccuracies in the production of vulnerable sounds, particularly in duration and spectral peak features. The results also revealed that the effects of mandibular disorder were much greater on the fricative consonants /z/, /s/, and /3/ relative to the other target sounds. Although the association was evident between both groups of mandibular disorder and misproduction of target sounds, the total mean variations of the acoustic parameters between the deviation and deflection groups did not reach statistical significance.

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## **The Effect of Mandibular Disorder on the Production of Vulnerable Consonant Sounds in Children**

### **1.0 Introduction**

Facial deformity and mandibular disorder are often associated with mispronunciation in speech sound production. Human speech sound production involves the coordinated articulation of the organs of speech in the oral cavity, nasal cavity, and organs located above and below the larynx and glottis, namely, tongue, upper and lower front teeth, lips, lower jaw, soft palate, and vocal cords. Some other parts, such as, pharynx, nasal cavity, upper jaw, and trachea, are also involved to a lesser extent. The mandible articulates to control the shape of the vocal tract and airflow required for sound production. Therefore, the lower jaw plays a crucial role in producing various sounds, especially fricatives, affricates, bilabials, laterals, and approximants. Therefore, when the jaw does not move properly, it can significantly affect how these sounds are made. (Roach, 2000)

The mandible is defined as “a U-shaped bone that connects to the base of the skull through two special joints called the temporomandibular joints (TMJs). These joints allow the jaw to move smoothly and freely, due to the muscles and ligaments that support them” (Adelusi, 2019, p.1).

Mandibular disorder is a common facial issue that happens when the teeth and jaws do not grow evenly. In such cases, one side of the jaw grows more than the other, which stops the upper and lower jaws from aligning properly (Hidajah, Ayu, and Syahru, 2021). Dental professionals and orthodontists diagnose this condition by examining the teeth and the shape of the lower jaw, or by using radiographic images. Both intraoral and extraoral examination are needed for a clear diagnosis. In the extraoral examination, the front view of the face is particularly important. In the cases when the midlines of the face and teeth do not match up, it indicates that there is a mandibular disorder. (Tsegga & Christensen, 2020)

According to Grunwell et al. (2000) and Hutters & Henningsson (2004) consonant sounds produced in actual articulation, are commonly classified into resilient ‘stable and strong’ and vulnerable ‘weak and unstable’ categories. Resilient sounds such as /p, b, k, t, tʃ/ tend to resist reduction or substitution. In contrast, vulnerable sounds, including /s/, /z/, /ʒ/, /dʒ/, /g/, /d/, /l/, and /n/ are less distinct and more likely to be reduced, change or affected by any deviation in speech organs such as, malocclusion, vocal cords dysfunction and jaw displacement. They require relatively precise articulatory control. More precisely, the production of fricative consonant sounds requires precise control of airflow and careful positioning of articulators. Their production highly depends on proper jaw movement. Any deviation in jaw movements may



affect the production of the consonant sounds, especially vulnerable ones. Since the abnormality in the upper organs of speech can affect the positioning of the tongue, lips, or teeth, leading to speech errors. (Kent& read, 2002; Stone, 2010; Hume,2011).

Although mandibular disorder has been widely investigated from dental and orthodontic perspectives, most studies have focused on its diagnosis and treatment. Comparatively less attention has been given to its acoustic consequences for consonant production. Furthermore, there are no acoustic studies demonstrating the relationship between mandibular dysfunction and the pronunciation of different consonant sound, particularly in children.

When it comes to children with temporomandibular disorder, they are expected to experience difficulties in speech production, especially with those sounds that are articulated in the anterior position of the oral cavity and require smooth jaw movement.

Considering the aforementioned problem and the gaps, the current study aims to investigate how jaw movement problems relate to mispronunciation of sounds and what the effects are of mandibular disorder on the production of the marked vulnerable consonants in children. It also seeks to find out which consonant is most affected by this condition. Accordingly, the study addresses the following research questions:

- 1.Does mandibular disorder have any effect on the production of vulnerable consonants in children?
- 2.Which vulnerable consonants show the greatest acoustic deviation from the reference values?
- 3.Which type of mandibular disorder has a greater effect on the production of vulnerable consonant sound: mandibular deviation or mandibular deflection?

## **2.0 Literature review**

### **2.1 Mandibular disorder: Definitions and types**

Mandibular disorder is also called temporomandibular joint (TMJ) disorder. It is defined as a shift of the lower jaw to one side during opening or closing due to muscle imbalances with the jaw joint (Widmalm, et al., 2016). Mandibular disorder or instability is also termed “a disorder in the development, shape and/or size of the jaw. Which can occur when human jaw growth does not fuse normally during early development causing dysfunction” (Nugent, 2011). Thus, this dysfunction affects the jaw joint and the surrounding muscles. While Jonson defined it

as “a group of conditions that affect the jaw joint and surrounding muscles due to inflammatory or mechanical factors.” (Johnson, 2012)

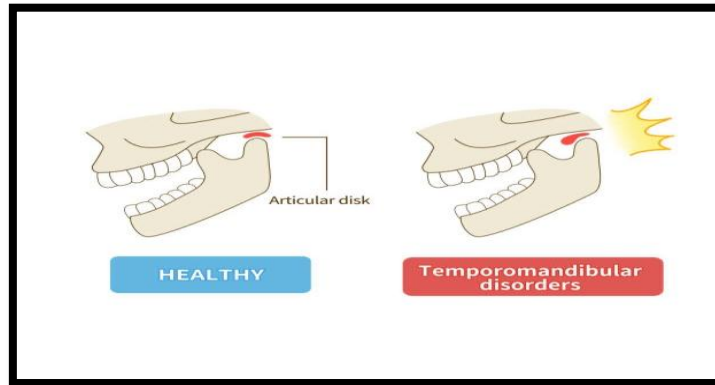


Figure (1) mandibular deviation sited from National institute of Dental and Craniofacial (NIDCR)

Mandibular disorder has two main types, deviation and deflection. Mandibular deviation relates to the lateral jaw movement. It involves the shift of the jaw to one side, right or left, during opening and returning to the midline position, especially when the mouth opens fully. Whereas jaw deflection is more significant. It occurs when the lower jaw shifts to one side, backward or forward, and remains there without returning to the centre, and this happens due to muscle incoordination. Mandibular deflection usually indicates a more serious structural problem, such as restricted movement of the jaw joint on one side. This type of mandibular disorder occurs due to disc displacement or joint limitation.

Both deviation and deflection are commonly attributed to mandibular instability or temporomandibular joint (TMJ) dysfunction. There are a number of conditions affecting the abnormality in the jaw joint, namely, surrounding muscles, and related structures. (Okeson, 2019)

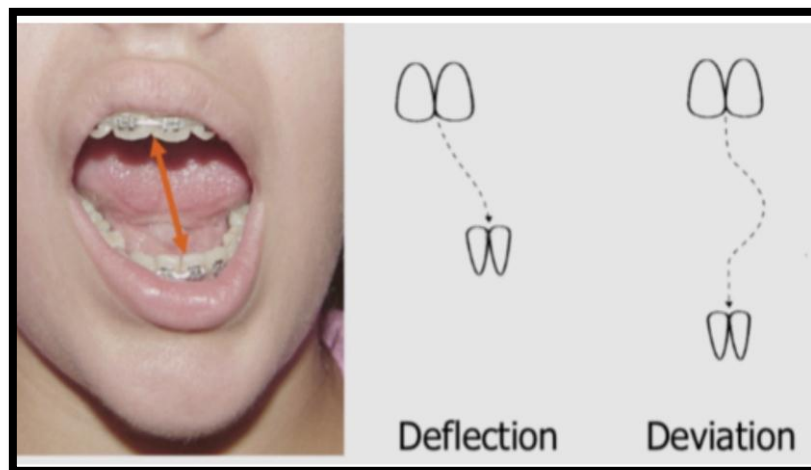


Figure (2) types of mandibular deviation as cited by Okeson, 2019

## 2.2 Articulatory and acoustic features of vulnerable consonants

The articulatory and approximate averaged acoustic characteristics of the vulnerable sounds have been documented by a number of phoneticians across different languages (Stevens,1998; Jongman, Wayland, & Wong, 2000; Dowson, 2003; Harrington ,2010), see Table 1.

Table (1) acoustic features of the vulnerable sounds

| Vulnerable sounds | Duration(ms) | Spectral peak (Hz) | Intensity(dB) | F2 Locus (Hz) |
|-------------------|--------------|--------------------|---------------|---------------|
| /s/               | ~140-160     | ~4000-8000         | ~15-20        | ~1700         |
| /z/               | ~80-100      | ~4000-7000         | ~20-25        | ~1750         |
| /ʒ/               | ~80-90       | ~2000-3000         | ~10-13        | ~2000-2200    |
| /dʒ/              | ~70-90       | ~2000-3000         | ~10           | ~2000-2100    |
| /d/               | ~60-100      | ~4000-4500         | ~ 10-12       | ~1800         |
| /g/               | ~60-110      | ~1500-2000         | ~ 15-30       | ~ 1850        |
| /n/               | ~50-100      | ~1500-2200         | ~10-15        | ~1800         |
| /l/               | ~50-80       | ~250-400           | ~65-80        | ~900-1500     |

Although the articulatory features of these consonant sounds are similar, they are not identical. They generally share a similar manner of articulation, voicing characteristics, and closely related place of articulation (O'Connor,1980; Ahmad,1986; Lindblom & Maddieson,1988; Ladefoged & Maddison,1996; Roach, 2009; Ladefoged & Johnson, 2015; Rahimpour & Dovaise, 2011; Mohammadi &Karimi Doostan, 2016).



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The vulnerable sound /s/ is produced in the anterior part of the oral cavity, with the tip of the tongue positioned close to the alveolar ridge and front teeth. This sibilant sound has a concentrated high spectral peak. Its frequency records approximately (4000–8000 Hz) a relatively long duration (~140-160 ms), and a gradual but sharp onset of friction noise. The sound intensity is approximately (15-20 dB) and its second formant is (F2 ~1700Hz) (Stevens,1998; Dowson, 2003). In addition, it is produced without vibration in the vocal folds (Lindblom & Maddison, 1988; Roach, 2009).

Another vulnerable sound is the voiced consonant /z/. Like /s/, it is a sibilant consonant but generally has a shorter duration (~80-100 ms). It is produced with a concentrated high peak (~4000-7000 Hz) accompanied by a gradual voiced friction with an intensity of approximately 20-25 dB and an F2 ~1750 Hz. (Jongman, Wayland, & Wong, 2000; Dowson, 2003).

The third vulnerable consonant is the sound /ʒ/. This postalveolar consonant sound typically has a short duration (~80-90 ms) and a concentrated lower peak (~2000-3000 Hz) accompanied by a gradual voiced noise (~10-13 dB, F2 ~ 2000-2200 Hz). This sound is characterized by continuous voiced friction. (Roach, 2009; Ladefoged & Johnson, 2015; Harrington, 2010; Rahimpour & Dovaise, 2011)

The vulnerable sound /dʒ/ is characterized by a short duration and a brief closure (~70-90 ms) followed by a release burst, then followed by noise similar to that of /ʒ/ (F2 ~ 2000 - 3000 Hz). It demonstrates a sharp rise in acoustic energy with a high formant (F2 ~ 2000-2100Hz), in addition to abrupt voiced noise (~10 dB). (Jongman, Wayland, & Wong, ,2010)

The vulnerable sound /d/ is characterized by its voice onset time rather than by friction duration. It is produced with a relatively short closure (~ 60-100 ms) followed by a burst release and a short voice onset time (F2 ~ 4000 – 4500 Hz). It has a low gradual voiced feature (F2~2000-2100Hz), in which the burst energy concentrated in the mid frequency region. In contrast, the vulnerable sound /g / is a stop-velar sound. It is produced at the velum in the posterior part of the oral cavity and characterized by a short closure (~ 60-100 ms), a relatively low spectral peak (~1500-2000 Hz), and a silent interval followed by a burst and voiced noise (~ 15-30 dB, F2~ 1850). Compared with /d /, this sound exhibits a longer voice onset time (O’Conor,1980; Ahmad,1986; Rahimpour & Dovaise, 2011; Jongman, Wayland, & Wong, 2000)

The final two vulnerable sounds are the nasal consonant /n/ and the lateral approximant consonant /l/. The nasal consonant /n/ is characterized by a variable but brief duration (~50-100 ms) and a very low peak (~1500 -

2200 Hz). It is produced with a nasal murmur and strong low- intensity (~10 -15 dB). It is also distinguished by the presence of and an antiformant frequency, which is differentiates nasals from other sonorant sounds (F2, ~1800Hz). In contrast, the lateral sound /l/ is recognized by a very short duration sonorant (~50- 80 ms) with a full formant structure that does not have a noise base (~250- 400 Hz, and F2 ~900-1500) and it is also characterized by a low- to- moderate intensity (~65-80 dB). (Stevens, 1998; Dowson, 2003; Harrington, 2010)

### **3.0 Methodology**

#### **3.1 Research design**

The current study adopted an exploratory case study design, using instrumental acoustic analysis, to investigate the effect of mandibular disorder on the production of invulnerable consonants in children with mandibular deviations. The exploratory case study was selected due to the detailed examination and unique advantage such an approach offers for understanding complex phenomena within their real-life contexts in the field of quantitative studies. (Paparini et al., 2020)

#### **3.2 Participants**

The study selected 11 children purposively aged between 10 and 13 who had been diagnosed with mandibular disorder by a specialist in orthodontics. Five of them suffered from mandibular deflection and six of them had mandibular deviation. All participants were Kurdish native speakers. the orthodontist reported that none of the children suffered from neurological, hearing, or cognitive impairments that could affect their speech production.

#### **3.3 Instrumentation and data collection procedure**

The oral data were collected from the participants via a high-quality digital recorder to capture the participants' speech production. The recorded speech data were subsequently analyzed using Praat, a prominent software program for acoustic phonetic analysis. The analysis focused on measuring the acoustic parameters of the target sounds, including duration, spectral peak, formant frequencies (F2), and intensity. In addition, to examine the acoustic effects of mandibular disorder on the speech production of the participants with mandibular deviation and mandibular deflection, the Mann-Whitney U test was employed to compare the differences in the acoustic measurement means of the target sounds between the two groups.





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During the data collection process, participants were asked to pronounce isolated vulnerable consonants and monosyllabic words containing the target consonants in word-initial, word-medial, and word-final positions. To enhance the reliability of the recordings, each speech item was produced three times, with a five-second interval between repetitions to minimize fatigue and carry-over effects.

### 3.4 Reliability

To ensure the consistency and stability of the tool, the study employed test - retest reliability. Participants' speech on two separate occasions was recorded. The duration between the two records was one week. To confirm the reliability, the acoustic measurement of two recordings was compared. The score of the **intraclass correlation coefficient** between the two recordings was (0.82) which indicates high reliability.

### 3.5 Ethical considerations

To ensure that the participants were aware of the purpose of the study, a consent form was designed by the researcher. Due to their young age, the participants were not eligible to provide informed consent. Therefore, the informed consents were obtained from their legal guardians. The consent form assured that the participants' identities would remain confidential and anonymous. It also stated that only the speech recordings and photographs of their mandibles would be used for the scientific purposes of the study. Based on these assurances, the parents signed the informed consent forms.

### 4.0 Results and findings

To ensure consistent data extraction, participants' speech recordings were analyzed using **Praat**, a prominent software program for acoustic phonetic analysis. The acoustic evidence showed that both types of mandibular dysfunction, deviation and deflection, were directly associated with the mispronunciation of vulnerable consonant sounds.

The acoustic analysis of each child's speech was compared with the normal acoustic ranges reported by Jongman, Wayland, and Wong (2000), Dowson (2003), and Harrington (2010), as presented in Table 1. The analysis measured different acoustic parameters, including duration, spectral peak, formants, and intensity.

The results of the duration analysis revealed the most consistent abnormality among the participants with both mandibular deviation and deflection. Almost all of the target sounds were produced with prolonged closure sequences and longer durations than those reported in the standardized model. The participants produced the sounds with durations

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ranging from 82 to 215 ms, whereas the corresponding durations in the standardized model ranged from approximately 50 to 160 ms.

The acoustic analysis also demonstrated that the fricative consonants /s/ and /z/ were pronounced with considerably longer durations by the participants with mandibular deviation than by those with mandibular deflection. For instance, Participant 3 produced the sound /s/ with a duration of 215 ms, followed by Participant 2, whose production lasted 205 ms. Regarding the sound /z/, Participant 3 produced it with a duration of 198 ms, while Participant 2 produced it with a duration of 191 ms. These average duration of /s/ and /z/ exceeded the standardized value reported by Harrington (2010) and Jongman, Wayland, and Wong (2000). Another sound that was produced with a considerably longer duration than that reported in the standardized model was /dʒ/. Its production lasted 194 ms for Participant 7, who had mandibular deflection, 175 ms for Participant 4, 164 ms for Participant 2, and 160 ms for Participant 5. Participants' speech recordings exceeded the standardized (70-90 ms) measurement reported by Ladefoged and Johnson (2015). See Table 2.

The acoustic analysis also demonstrated that the duration of the sound /n/ in the participants' speech recordings exceeded the normal average duration reported in the literature, which ranges between 50 and 100 ms. Almost all the participants required a longer time to produce it. The longest durations, as illustrated in Table 2, were recorded for Participant 7 (128 ms), followed by Participant 5 (118 ms), Participant 10 (112 ms), Participant 2 (106 ms), and Participant 1 (104 ms) and participant 9 (103 ms). The differences in closure and duration occurred because the articulators moved more slowly and less efficiently than those of normal speakers. The acoustic analyses also showed a reduction in the oral constrictions necessary for vulnerable consonants' production. These problems were directly associated with mandibular instability. This result confirms what Stone (2010) argued that any disturbance in the articulators will affect sound timing variability.

Table 2 the acoustic analyses of the participants' speech records

|    | Vulnerable sounds | Duration(ms) | Spectral peak (Hz) | Intensity(dB) | F2 Locus (Hz) |
|----|-------------------|--------------|--------------------|---------------|---------------|
| P1 | /s/               | 192          | 6450               | 66            | 1810          |
|    | /z/               | 184          | 4850               | 64            | 1765          |
|    | /ʒ/               | 168          | 3520               | 61            | 1700          |
|    | /dʒ/              | 158          | 3320               | 62            | 1695          |
|    | /d/               | 82           | 3500               | 70            | 1750          |



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|    |      |     |      |      |      |
|----|------|-----|------|------|------|
| P2 | /g/  | 88  | 1098 | 69   | 1580 |
|    | /n/  | 104 | 1012 | 67   | 1715 |
|    | /l/  | 112 | 1079 | 66   | 1792 |
|    | /s/  | 205 | 6280 | 64   | 1795 |
|    | /z/  | 191 | 4705 | 63   | 1740 |
|    | /ʒ/  | 174 | 3450 | 60   | 1685 |
|    | /dʒ/ | 164 | 3245 | 60   | 1670 |
|    | /d/  | 84  | 2023 | 69   | 1735 |
|    | /g/  | 91  | 2078 | 68   | 1565 |
| P3 | /n/  | 106 | 1019 | 66   | 1700 |
|    | /l/  | 116 | 1889 | 65   | 1780 |
|    | /s/  | 215 | 6125 | 63   | 1770 |
|    | /z/  | 198 | 4620 | 62   | 1715 |
|    | /ʒ/  | 87  | 1230 | 68   | 1710 |
|    | /dʒ/ | 94  | 1244 | 67   | 1550 |
|    | /d/  | 108 | 2030 | 65   | 1680 |
|    | /g/  | 119 | 1988 | 67   | 1765 |
|    | /n/  | 102 | 1007 | 60.1 | 1730 |
| P4 | /l/  | 112 | 4853 | 46.5 | 1647 |
|    | /s/  | 138 | 5414 | 50.8 | 1540 |
|    | /z/  | 120 | 4808 | 53   | 1516 |
|    | /ʒ/  | 140 | 2963 | 58.9 | 1394 |
|    | /dʒ/ | 175 | 2189 | 60   | 1730 |
|    | /d/  | 98  | 1741 | 60.4 | 1536 |
|    | /g/  | 108 | 1842 | 60.1 | 1930 |
|    | /n/  | 90  | 1002 | 58.7 | 1632 |
|    | /l/  | 121 | 1695 | 60   | 1427 |
| P5 | /s/  | 189 | 3787 | 48.2 | 1426 |
|    | /z/  | 146 | 5087 | 53   | 1521 |
|    | /ʒ/  | 145 | 2176 | 58.8 | 1435 |
|    | /dʒ/ | 160 | 1790 | 60.6 | 1611 |
|    | /d/  | 81  | 1286 | 56.8 | 1436 |
|    | /g/  | 99  | 2032 | 55.7 | 1531 |
|    | /n/  | 118 | 1011 | 60.7 | 1414 |
|    | /l/  | 110 | 1050 | 66.6 | 1633 |
| P6 | /s/  | 134 | 5991 | 44.5 | 1638 |
|    | /z/  | 137 | 5266 | 56.1 | 1813 |
|    | /ʒ/  | 140 | 2382 | 49.5 | 1634 |
|    | /dʒ/ | 150 | 2893 | 54.7 | 1712 |

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|     |      |     |      |      |      |
|-----|------|-----|------|------|------|
|     | /d/  | 93  | 1570 | 57.8 | 1782 |
|     | /g/  | 98  | 1654 | 53.9 | 2049 |
|     | /n/  | 97  | 990  | 60.5 | 1850 |
|     | /l/  | 88  | 1942 | 62   | 1617 |
| P7  | /s/  | 195 | 5904 | 52.5 | 1575 |
|     | /z/  | 117 | 4338 | 52.8 | 1472 |
|     | /ʒ/  | 122 | 2259 | 58.7 | 1361 |
|     | /dʒ/ | 194 | 2476 | 50.7 | 1552 |
|     | /d/  | 108 | 1646 | 60   | 1501 |
|     | /g/  | 92  | 2352 | 56.9 | 1902 |
|     | /n/  | 128 | 912  | 63.5 | 1496 |
|     | /l/  | 122 | 1283 | 65.8 | 1399 |
| P8  | /s/  | 157 | 5906 | 45.6 | 1607 |
|     | /z/  | 137 | 4322 | 58.4 | 1738 |
|     | /ʒ/  | 124 | 2836 | 55.3 | 1765 |
|     | /dʒ/ | 143 | 3183 | 50.2 | 1595 |
|     | /d/  | 84  | 1691 | 58.1 | 1838 |
|     | /g/  | 74  | 1934 | 62.7 | 1934 |
|     | /n/  | 84  | 971  | 61.9 | 1820 |
|     | /l/  | 109 | 1919 | 61.2 | 1617 |
| P9  | /s/  | 181 | 5160 | 54.7 | 1575 |
|     | /z/  | 106 | 5247 | 55.2 | 1577 |
|     | /ʒ/  | 165 | 2046 | 50.5 | 1356 |
|     | /dʒ/ | 177 | 2323 | 54.2 | 1529 |
|     | /d/  | 76  | 1746 | 57.4 | 1607 |
|     | /g/  | 112 | 2257 | 53.9 | 1777 |
|     | /n/  | 103 | 1009 | 67.4 | 1571 |
|     | /l/  | 91  | 1652 | 63.1 | 1521 |
| P10 | /s/  | 124 | 6670 | 52.3 | 1765 |
|     | /z/  | 131 | 5345 | 52.2 | 1652 |
|     | /ʒ/  | 116 | 3320 | 56.7 | 1788 |
|     | /dʒ/ | 170 | 2559 | 48.8 | 1543 |
|     | /d/  | 85  | 2177 | 57.2 | 1859 |
|     | /g/  | 74  | 2698 | 59.6 | 1979 |
|     | /n/  | 112 | 908  | 57.4 | 1816 |
|     | /l/  | 83  | 2004 | 64.2 | 1851 |
| P11 | /s/  | 153 | 5631 | 44.1 | 1633 |
|     | /z/  | 150 | 3854 | 60.8 | 1535 |
|     | /ʒ/  | 131 | 2808 | 52   | 1337 |



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|  |      |     |      |      |      |
|--|------|-----|------|------|------|
|  | /dʒ/ | 157 | 2401 | 57.4 | 1606 |
|  | /d/  | 78  | 1757 | 58.9 | 1707 |
|  | /g/  | 98  | 2390 | 54.3 | 1816 |
|  | /n/  | 98  | 974  | 61.9 | 1451 |
|  | /l/  | 99  | 1651 | 60.6 | 1569 |

The results obtained from the acoustic analysis revealed that there was instability in the spectral peak across participants' production of the target sounds. The deviations mainly affected the production of fricative vulnerable sounds articulated in the alveolar and post alveolar region. More precisely, the greatest variability occurred in /dʒ/, /ʒ/, /s/, and /z/, in terms of formant and peak values respectively. In contrast, the least variability occurred with the sound articulated in the nasal cavity/n/ as shown in Figure 3. The spectral peak in the participants' acoustic analyses revealed that the displaced mandible among the participants, particularly those with mandibular deflection, altered the size of oral passages beyond what was required to create friction.

Table 2 shows that the mean peak of the sound /dʒ/ ranged from 2198 to 3183 Hz, /ʒ/ ranged from 2046 to 3320 Hz, /z/ ranged from 3854 to 5938 Hz, /s/ ranged from 3787 to 6670 Hz, across the participants. In contrast, the mean spectral peak of the sound /n/ remained stable and close to the given standardized values, with values ranging from 908 to 1019 Hz across the participants. These findings are in parallel with what Jongman et al. (2000) claimed. In their study, they demonstrated that the spectral peak and frequencies of the fricative and affricate sounds are highly affected by any dysfunction in articulators.

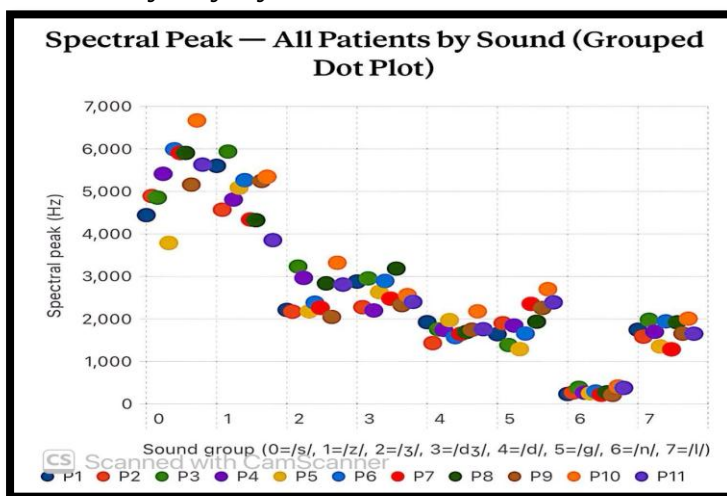


Figure 3 participants' means of the spectral peak

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The following dot plot figure illustrates the mean acoustic features of the examined sounds produced by each participant. The results indicate that duration and intensity, as shown in the figure 4, exhibited greater deviation than the other two acoustic features, frequency and spectral peak.

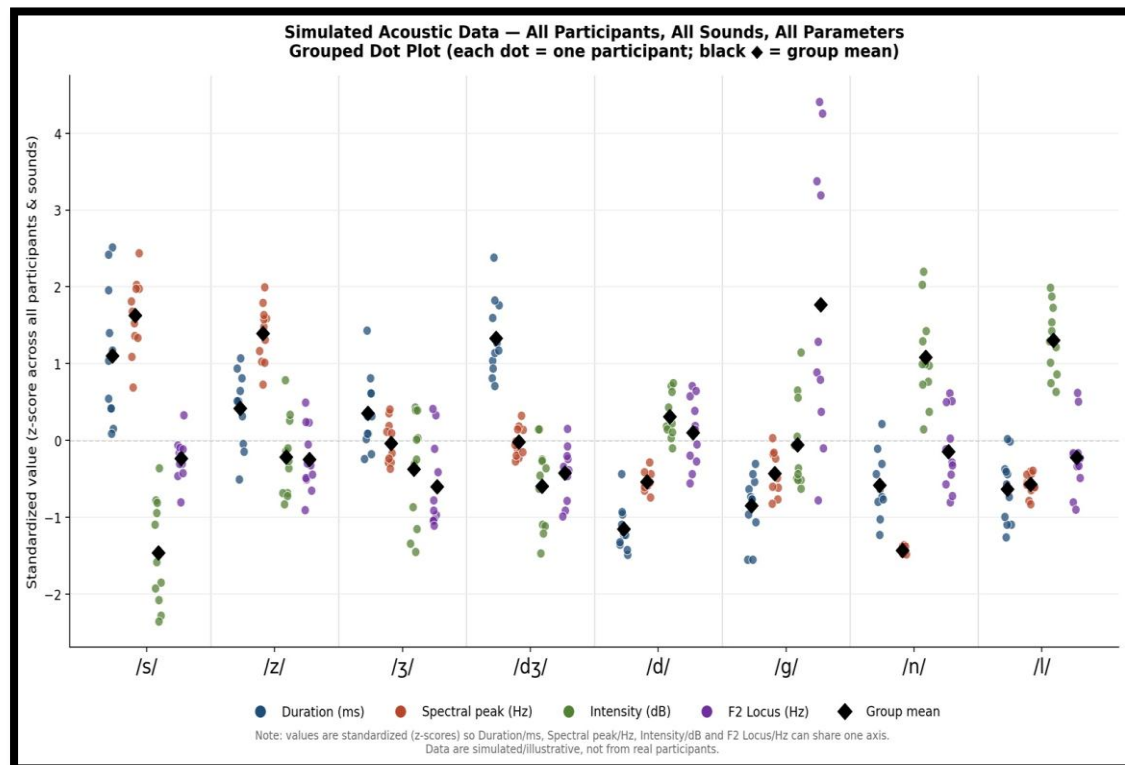


Figure 4 acoustic means and parameters of target consonants as pronounced by participants

To investigate the effects of mandibular disorder, the intensity in the participants' voice recordings was also analyzed. Acoustic analysis showed that the intensity of the target vulnerable sounds produced by the participants had decreased. However, the extent of this reduction varied across the target sounds. Likewise, the degree of change was not consistent across all participants. In other words, the effect of mandibular deviation differed according to the sound being produced and the effects were not similar among all participants.

Table 3 Participants' speech intensity means

| Sound class               | Mean intensity | Standard deviation |
|---------------------------|----------------|--------------------|
| /s /voiceless fricative   | 4.89           | ~13.7              |
| /dʒ/voiced affricate      | 5.35           | ~12.9              |
| /z/, /ʒ/ voiced fricative | 5.50           | ~12.7-~12.8        |
| /d/, g/ stops             | 5.73           | ~10.5-~11.0        |
| /n/, /l/ sonorants        | 6.30           | ~10.3 - ~10.6      |

The results demonstrated that the sonorant vulnerable sounds /l/ and /n/ exhibited higher intensity value than fricative, affricate and stop sounds, as shown in Table 3. The average mean of their intensity was approximately 6.30 with a standard deviation ranging from ~10.3 to ~10.6. The stop sounds /d/ and /g/ had a mean intensity of approximately 5.73 with a standard deviation ranging from ~10.5 to ~11.0. The voiced fricative /z / and /ʒ/ showed a mean intensity of 5.50 with standard deviations between ~12.7 and ~12.8. Whereas the voiced affricate /dʒ/ had a mean intensity of 5.35 with a standard deviation of approximately 12.9. The voiceless fricative /s/ exhibited the lowest mean intensity, approximately 4.89 with a standard deviation ~13.7. Overall, the findings indicate progressive decrease the intensity from the sonorant sounds to stops and finally to fricative and affricate sounds.

Furthermore, the findings suggested that the sound intensity of participants with mandibular defections were affected more than those with mandibular deviation, this difference was likely attributed to the retruded jaw placement which restricted normal articulatory movement than did the lateral jaw displacement observed in participants with mandibular deviation. These obtained results confirm what Kent and Read's claim which stated that articulation disorders directly affect the airflow as well as the vocal effort.

The fourth acoustic feature, the frequency locus (F2), in participants' recorded speech was also affected by mandibular disorder and instability. The frequency analysis revealed that the production of all eight examined sounds was affected, although not to the same extent. Mandibular disorder affected jaw and tongue movements, which are essential components of the oral cavity. Since these sounds depend on accurate tongue-body positioning, any disturbance in these articulators alters the frequency of the produced sounds. Based on the obtained data, the mean

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F2 values of the vulnerable alveolar sounds /s/, /z/, /d/, /n/, and /l/ were relatively close to one another, ranging from 1593 to 1697 Hz. The overall mean F2 value for this group was 6.217 with a standard deviation of 12.97. These frequencies were relatively close to the standardized formant values presented in Table 1. In contrast, the mean F2 values of the vulnerable sounds /ʒ/, /dʒ/, and /g/ differed more markedly from those of the other target sounds. The F2 values of the post-alveolar sounds /ʒ/ and /dʒ/ ranged from 1486 to 1563 Hz. Their mean F2 value was 5.135, with a standard deviation of 14.03.

Table (4) frequency F2 means of the target sound

| Sound groups    | Frequency means | SD    |
|-----------------|-----------------|-------|
| /s, z, d, n, l/ | 6.217           | 12.97 |
| /ʒ, dʒ/         | 5.135           | 14.03 |
| /g/             | 2.192           | 22.98 |

In contrast, the vulnerable sound /g/ showed the greatest effect. The frequency locus (F2) ranged from 1898 to 1923 Hz. Its mean F2 value was 2.192, with a standard deviation of 22.98, indicating greater variability among the participants (see Table 4).

The current findings agree with Jongman et al. (2000), who confirmed that tongue-body positioning has a considerable influence on the frequency characteristics and formant structure of speech sounds.

The above results answered the first research question, which addressed to investigate the effects of mandibular disorder on the production of vulnerable sounds by children with mandibular deviation and mandibular deflection. To answer the second and third research questions, which examined which vulnerable sounds were most affected and which types of mandibular disorder had the greater effect on the participants' speech production, the total mean values of the vulnerable sounds obtained from the acoustic analysis were compared using the Mann-Whitney U test. In addition, the total mean effects of the two types of mandibular disorder (deviation and deflection) were also compared. The results are presented in Tables (5 and 6). Table 5 illustrates the most affected sounds after measuring the deviation of the acoustic feature values in comparison with the standardized acoustic measurements reported for normal speakers within the same age group as the study participants. The results revealed that the vulnerable sound /z/ was affected more than the other sounds based on the normative values across the four acoustic parameters, with a mean average of 25.1. This was followed by the sound /s/, with a total mean effect of 21.4, and then the sound /ʒ/, with a mean of 20.7. The



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reason behind the greater changes in these sounds is that the instability of jaw movement affects the degree of closure. These sounds are normally produced with clear friction and longer duration than stop, sonorant, and lateral sounds. Intensity, spectral peak, and frequency are three acoustic features that are expected to be higher in fricatives. However, mandibular deviation and deflection reduce these features. For this reason, the pronunciation of these sounds appeared less natural. In contrast, the pronunciation of the sound /l/ was the least affected, with a mean effect of 16.3. Under normal conditions, the lateral sound requires a shorter duration with continuous gliding airflow. As the results revealed, mandibular disorder had a lesser effect on these two features of this sound. Another sound that showed a lesser effect was /n/, a sonorant nasal sound. This sound is produced through the nasal passage. It requires a shorter duration and lower intensity and frequency in comparison with /s/, /z/, and /ʒ/. The results revealed a mean of 17.1, indicating that the blocked bite caused by mandibular disorder did not have a substantial effect on the production of this sound.

Table 5. Total acoustic value across target sounds and mandibular disorder effect ranking

| Rank | sounds | Sound duration mean | Spectral peak mean | Intensity mean | Frequency mean | Effect index % |
|------|--------|---------------------|--------------------|----------------|----------------|----------------|
| 1    | /z/    | 5.49                | 5.33               | 5.55           | 4.95           | 25.1           |
| 2    | /s/    | 3.42                | 4.94               | 4.89           | 4.93           | 21.4           |
| 3    | /ʒ/    | 3.21                | 3.82               | 4.46           | 4.86           | 20.7           |
| 4    | /d/    | 3.19                | 3.63               | 3.83           | 3.69           | 20.2           |
| 5    | /dʒ/   | 2.89                | 2.63               | 3.53           | 3.40           | 19.8           |
| 6    | /g/    | 2.61                | 2.35               | 3.36           | 2.92           | 19.6           |
| 7    | /n/    | 1.95                | 1.93               | 2.62           | 1.67           | 17.1           |
| 8    | /l/    | 1.35                | 1.86               | 2.35           | 1.99           | 16.3           |

To determine which type of mandibular disorder had the greater effect on the pronunciation of the target sounds, the acoustic analyses of the participants' recorded speech were compared. Although the acoustic parameters of both groups demonstrated that the pronunciation of the target sounds was affected by mandibular disorder, none of the comparisons reached statistical significance ( $p < .05$ ), as shown in Table 6. This indicates that both groups were similarly affected by mandibular instability. Despite the overall similarity in the effects, the duration values

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of the mandibular deviation group appeared to be more affected than those of the mandibular deflection group, showing a medium-to-large effect size ( $r = -0.53$ ).

Table 6. Mann Whitney U deviation(P1-6) vs Deflection (P7-11) participant- level median

|                    | Mandibular deviation | Mandibular deflection | U    | P-value | Rank  |
|--------------------|----------------------|-----------------------|------|---------|-------|
| Duration           | 3.09                 | 3.50                  | 23.0 | 0.178   | -0.53 |
| Spectral peak      | 2.81                 | 2.68                  | 17.0 | 0.792   | -0.13 |
| Intensity          | 4.60                 | 5.06                  | 24.0 | 0.126   | -0.60 |
| Frequency Locus F2 | 2.31                 | 2.81                  | 16.0 | 0.731   | -0.07 |

In contrast, the intensity values of the mandibular deflection group were more affected ( $r = -0.60$ ), which also represents a moderate-to-large effect size according to conventional benchmarks. Meanwhile, the rank values for spectral peak and frequency were similar between the two groups. See Figure(5).

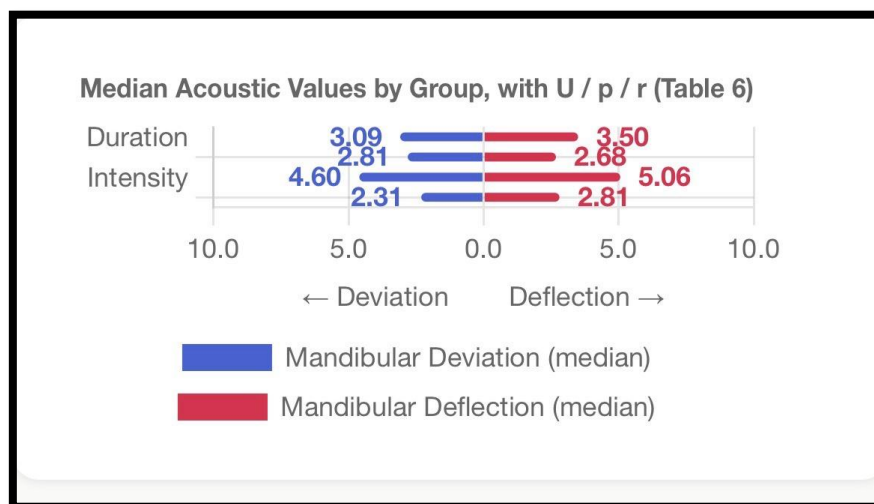


Figure (5) median acoustic value of mandibular types with Mann Whitney U

### 4.2 Discussion

The results obtained from the acoustic analysis of eight vulnerable consonant sounds, namely, /s/, /z/, /ʒ/, /dʒ/, /g/, /d/, /l/, and /n/, across



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eleven participants with mandibular disorders investigated the effects of mandibular instability by measuring the acoustic effects and parameters such as sound duration, spectral peak, intensity, and frequency locus (F2). The obtained results were compared with the acoustic features reported for normally produced consonants in studies by Stevens, 1998; Jongman, Wayland, & Wong, 2000; Dowson, 2003; Harrington, 2010. These studies provided established acoustic measures that were validated and utilized reference value in the current study. Therefore, the results were discussed in relation to the acoustic and articulatory features reported by these studies.

The study also aimed to identify which of these vulnerable sounds across the tested consonants was more affected by mandibular disorder. In addition, it drew a distinction between the acoustic patterns of the analyzed sound uttered by children with mandibular deviation and those with mandibular deflection. In this way, the findings address the three research questions of the study.

To determine the general effect of mandibular instability on the production of the target sounds, the acoustic results provided evidence that the mandibular disorder caused variations in all the acoustic characteristics of the target sounds and led to misproduction, although the degree of effects differed across the acoustic parameters. Among the four measured parameters, sound duration exhibited the most consistent deviation compared to the other acoustic features. The participants generally pronounced the target sounds with longer duration compared to the reference values. This may be due to the difficulty the participants experienced in positioning the articulators in the correct area during the production of sounds before placing them in positions required for the target sounds. As it is clear, the production of the consonants requires the articulators to maintain specific positions inside the oral cavity within an appropriate period of time and then to moving towards the following sound. Because of the mandibular deviation and deflection, the participants may have had difficulty achieving the precise place of articulation required for production. Consequently; this instability slowed the movement of the jaw and resulted in longer sound duration. This interpretation, as mentioned previously, is inconsistent with what Jongman, Wayland, & Wong, 2000; Roach, 2000; Stone, 2010, who reported that each consonant sound requires accurate duration requires appropriate articulatory place, manner, and voicing to be produced accurately. Any disturbance of the articulatory process can therefore affect both the quality and quantity of the sound.

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The results, also revealed that among the target consonants, /z/, /s/, and /ʒ/ were more affected by the jaw displacement and showed the highest mean intensity and spectral value, while /z/ appeared to have the longest duration. These findings address the second research question. The duration and intensity measures demonstrated greater variation in these sounds, as indicated by their mean values. The acoustic results, when analyzed by Mann-Whitney U, together with the articulation observation demonstrated that greater deviation on these three sounds may relate to their articulatory requirements. The changes in the duration and intensity were due to the altered shape and efficiency of the oral tract which affected the of the air flow and reduction in their energy. Clearly, the quality of the friction depends on the narrow passage formation and the volume of airflow. In other words, the fricative vulnerable sounds heavily depend on the inner diameter of the passage to make the friction and intensity more audible. Furthermore, any problem in the oral configuration will limit the normal return of the mandible to its normal position and affects efficient air flow. Another reason was the lack of enough energy in the sound production process necessary for pronouncing these sounds accurately. These results confirm what Kent and Read's (2002) claim which emphasized the influence of air flow on the fricative sound production.

The frequency (F2) analysis of the participants' speech records also showed variation in the frequency pattern of the vulnerable sounds /ʒ /, /dʒ/, particularly /g/. The analysis aligned with what Jongman et al. (2000) emphasized. The acoustic analysis highlighted the importance of the articulatory positioning for the frequency and formants of the consonant sounds' production. The change observed in the altered F2 patterns of these three sounds, more precisely /g/, may be related to their place of articulation. The posterior place of articulation of the mentioned sounds, depends heavily on the tongue body movement towards the palatal and velar region of the oral cavity. The instability of the mandible may interfere with the tongue body correct movement and make it difficult for the tongue to maintain the required articulatory position, leading to inaccurate pronunciation.

In contrast the vulnerable sounds /d/, / n/, and /l/ showed the least variation in their formant pattern. This may be due to their place of articulation. Nasals and alveolar sounds, which require a relatively frontal oral configuration; thus, changes in the acoustic features may affect them least, in comparison with sounds produced in the posterior oral cavity. However, the interpretation should be considered cautiously since the production of vulnerable sounds involves coordination among the organs.



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Finally, the total mean comparison of the acoustic patterns, produced by patients with both types of mandibular disorder, deviation and deflection, showed no clear overall differences between the two groups. that the effect of mandibular disorder was almost similar on the production of the vulnerable sounds. Since the consonant sounds' production depends heavily on a precise and stable oral constriction.

### **5.Conclusions**

The current study, as mentioned above examined the effects of mandibular disorder on the production of vulnerable consonant sounds (/s/, /z/, /ʒ/, /dʒ/, /g/, /d/, /l/, and /n/) in children with mandibular problems, specifically mandibular deviation and mandibular deflection. The sample consisted of only eleven participants. Therefore, the results are limited to the participants and research setting.

The results and findings revealed that the mandibular instability was directly associated with misproduction of vulnerable consonants. However, the acoustic characteristics affected were neither uniform nor limited to a single acoustic feature. The effects took the form of prolonged duration in several of the analyzed sounds, namely /z/, /s/, and /ʒ/. The reason behind the prolonged duration is probably due to the difficulty establishing and maintaining oral configuration. Similarly, the results demonstrated variation in the acoustic spectral peak of the analyzed sounds, particularly the posterior vulnerable sound/g/ and palatal affricate/dʒ/, and a fricative sound /ʒ/, which resulted from inaccurate positioning of the tongue body within the oral cavity. In addition, some variation in frequency was observed as a consequence of altered oral configuration.

The acoustic analysis confirmed that the greatest effects were observed in the vulnerable fricative consonants, /z/, /s/, and /ʒ/, whereas the vulnerable nasal and lateral consonants /l/ and /n/ were comparatively less affected.

Although, both types of mandibular disorder, deviation and deflection were association with altered consonant production, comparison of the mean variation of between the two groups, conducted to identify which type of jaw instability had a greater effect, revealed no statistical significance, as the effects of the two groups were closely comparable. It is therefore concluded that accurate production of vulnerable consonant requires a highly precise oral constriction, since any change in jaw positioning or movement results in consonant sound mispronunciation.



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