Original Article

Effects of Hawley retainers on consonants and formant frequencies of vowels

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ABSTRACT

Objective: To assess (1) whether Hawley retainers cause speech disturbance and (2) the duration of speech adaptation to Hawley retainers with objective and subjective tests.

Materials and Methods: Twelve adolescents, aged 11.11 to 18.03 years, were included in this study. The assessment of speech sounds were done subjectively using an articulation test and objectively using acoustic analysis before and after Hawley retainer application.

Results: After wearing Hawley retainers, patients showed statistically significant speech disturbances on consonants [ş] and [z]. Regarding the vowels, statistically significant changes were recorded with [i], while F1 increased and F2 and F3 decreased.

Conclusions: The tongue changes its target position with the application of a foreign body within the mouth; however, in time it adapts to that new situation. (*Angle Orthod.* 2012;82:14–21.)

KEY WORDS: Hawley retainer; Speech articulation; Formant frequencies

INTRODUCTION

Retention is the phase of the orthodontic treatment that prevents the tendency toward relapse and maintains the occlusal stability achieved at the end of the active treatment.[1] The etiology of relapse is not fully understood, but it relates to a number of factors, including periodontal and occlusal factors, soft tissue pressures, and growth.[2] To prevent the teeth from returning to their initial positions (relapse), almost every patient who has orthodontic treatment will need to use either a removable or a fixed retainer.

The Hawley retainer is one of the most used removable retainers and fits against the lingual surfaces of teeth, palate, and lingual mucosa in the maxillary and mandibular arches. There is no required duration of retention, although it has been shown that at least in relation to periodontal factors it takes, on average, a minimum of 232 days for fibers around the teeth to remodel to the new tooth position.[3] In the long term, retention might be necessary until growth is complete or indefinitely if teeth are in unstable positions. Some patients find the retainers to be more unacceptable than their fixed appliances. The reasons given for patients' intolerance of retainer wear for this long term include difficulty in speaking or eating, smell because of the oral hygiene problem and embarrassment.[4,5]

Speech production can be affected by any osseous, muscular, dental, or soft tissue deformity or by any device that impairs the movement or appearance of the speech sound articulators.[6,7] The effects of orthodontic appliances on speech have been extensively studied[8–10] during the past decades. In most cases the impairment is temporary, varying in length from a few days to a few weeks; however, Stewart et al.[11] reported speech problems lasting up to 3 months. The design modifications of the Hawley retainer also affect speech production. Stratton and Burkland[10] tested the effects of various designs of maxillary retainers on the clarity of speech at initial placement and concluded that Crozat-type and modified horseshoe-shaped retainers are superior to the traditional Hawley design. The authors concluded that reducing the acrylic coverage seemed to be the key to limiting speech difficulties and increased patient comfort. Dental appliances might cause articulatory production distortions as a speech production

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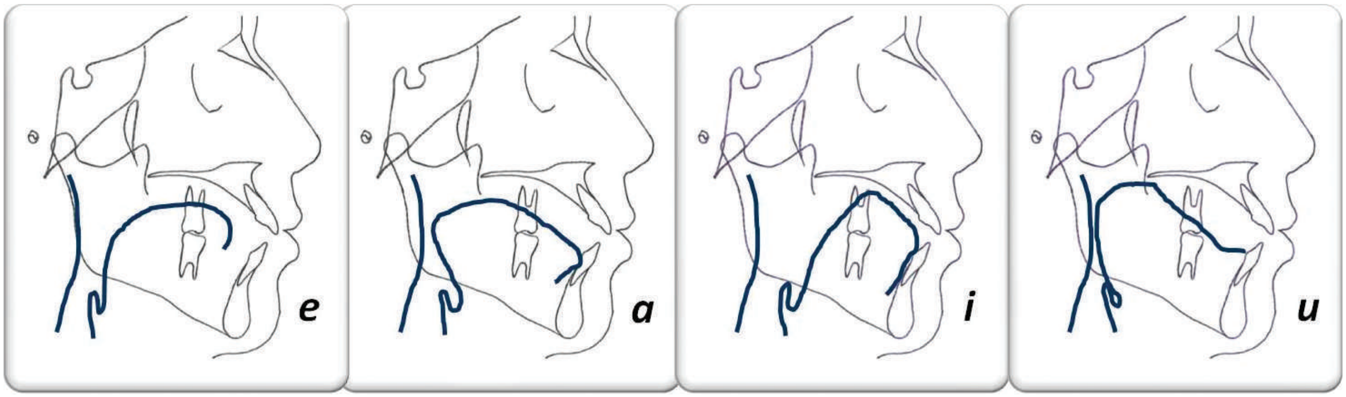

Figure 1. The tongue positions in the oral cavity while creating the formants of the [a, e, i, u] vowel sounds.

error in which a speech sound is recognizable as the correct sound but is not produced exactly correct. The most common distortions are labiodentals [f, v] or linguoalveolar [d, t, s, z] consonants, but these disruptions are minimized after a short period of retainer wear as a result of functional adaptation.[12]

The effect of retainers on speech articulation can also affect the formation of vowels as well as consonants. During the production of vowel sounds [a, e, ı, i, o, ö, u, ü] (Turkish vowels) the shape of the supralaryngeal vocal tract continually changes; thus, several resonances, ranging from low frequency to

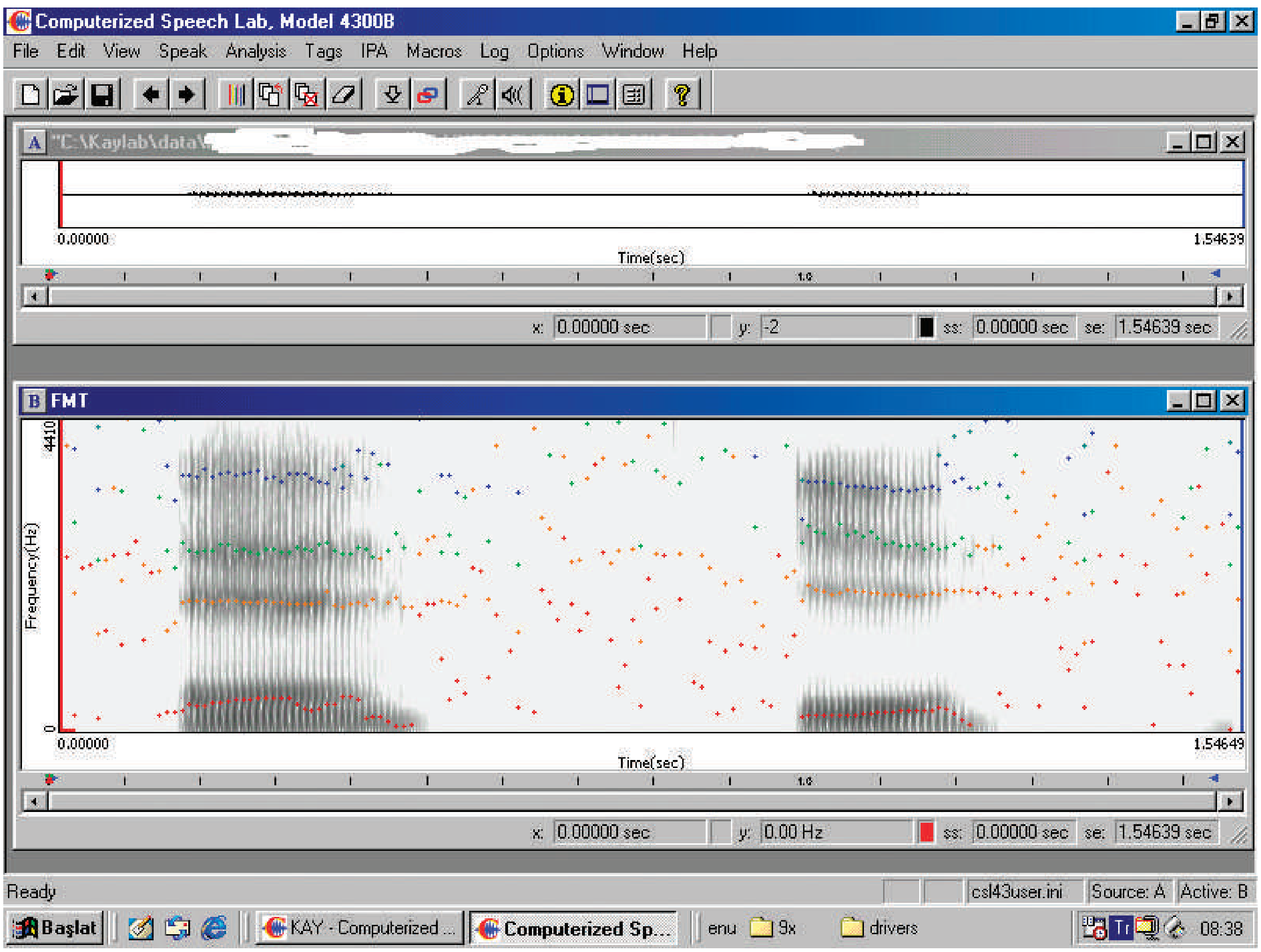

Figure 2. Spectrogram of vowels [e and i].

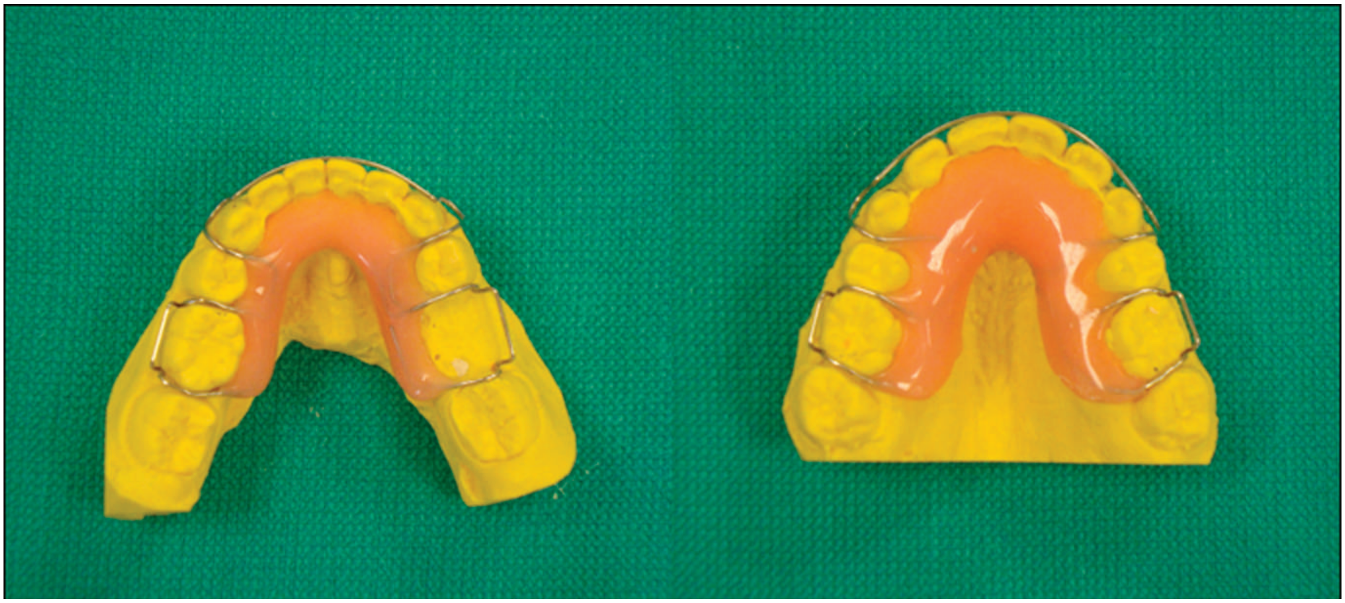

Figure 3. Upper and lower Hawley retainers used in present study.

Figure 4. Acoustic test records used in this study.

high frequency and produced by positioning the articulators in the vocal tract, and a set of articulatory parameters are used to describe them: the highest point of the tongue on the horizontal axis (front, back), the highest point of the tongue on the vertical axis (close, open), and lip shape (rounded, unrounded)[13,14] (Figure 1). Thus, a particular combination of articulator positions is associated with a vocal tract shape, which is in turn associated with a particular pattern of resonances. The resonances of the vocal tract are called formants.[15] Formant frequencies are determined by the length and shape of the supralaryngeal vocal tract. Formants are visible on an acoustic display of speech as pronounced bands of energy such as spectrograms (Figure 2).

Formant frequencies represent an objective measure that may be useful in studying the effects of treatment on vocal function. Formants are the resonant harmonics in the speech spectrum and are described[16,17] as being the characteristic partials that help identify the vowel to the listener. Formants are believed to be responsible for the phonetic characterization of vowel quality and are essential components in the perception of speech.[16,17]

The primary acoustic correlates of vowel identity are the first formant frequency (F1) and the second formant frequency (F2); F1 is associated with tongue height and F2 is associated with the anterior-posterior position of the tongue.[18] The third formant frequency (F3) is more dependent on the shorter back cavity.[19] The movements of the articulators set the limits of variation, which in the spectral domain are typically seen as variation in the formant frequencies.

There are many studies[6,9,10,20–23] whose authors have used subjective evaluation of the consonants and vowels and who have reported effects of the orthodontic application on the speech articulation in the literature, whereas fewer studies[13,24–27] contained objective assessment of the formant frequencies.

The aim of this study was to investigate the effects of Hawley retainer application on speech sounds with regard to objective acoustic evaluation of vowels and subjective articulation assessment of consonants.

MATERIALS AND METHODS

This study was approved by the Hacettepe University Ethical Board (08A101014). The participants in this study comprised 12 adolescents (three males, nine females) aged between 11.11 and 18.03 years (mean age: 14.97 ± 2.64 years). All participants were native Turkish speakers who had been raised in a monolingual environment. At the first appointment, the articulation abilities of 12 patients were evaluated before the initiation of retainer wear. At the beginning of the orthodontic treatment, six of the patients had Angle Class II malocclusions and the remaining six patients had Angle Class I malocclusions; four of these cases involved treatment with extractions.

Hawley retainers were constructed with an acrylic base plate, Adams clasps, and a labial bow with vertical loops soldered to the Adams clasps. The acrylic part of the retainer was maintained at a uniform thickness of 2 mm to 3 mm and was trimmed even thinner behind the maxillary incisor area. The maxillary retainer was constructed in a slight horseshoe shape, and both retainers had circumferential bows (Figure 3). The patients were instructed to wear the retainers 24 hours a day for 6 months, including while eating, but to remove them when brushing their teeth.

Procedure

The assessments of speech sounds were done subjectively using an articulation test and objectively using acoustic analysis. Both types of assessment were performed at four different time points, as follows: (1) on the first day, (2) 1 week later, (3) 4 weeks later, and (4) 3 months later. On the first day, the assessments were done prior to application of retainers, immediately following wear of maxillary and mandibular retainers, respectively, and with both retainers worn together. The other assessments were done while both retainers were worn.

Articulation Test

The articulation test was done before the acoustic analysis according to the principles described by Haydar et al.[9] using nonsense syllables. Each participant's articulation test was analyzed on site by the speech-language pathologist, and each nonsense syllable that was judged to be distorted was marked. The patients who didn't have any articulation problems before wearing any retainers were included in this study.

Acoustic Analysis

The vowel sounds depend on the two dimensions/positions of the tongue: high-low and front-back. In this study we measured the acoustic features of [i, e, a, u] vowels as [i] being high-front, [e] being low-front, [u] being high-back, and [a] being low-back (Figure 1). Acoustic analysis was performed using Computerized Speech Lab Model 4300B (Kay Elemetrics Corp, Lincoln Park, NJ) to measure formant frequencies F1, F2, and F3 in the voice laboratory.

All participants were given a practice trial for each task following the clinician's model, in order to assure the individual's best production. During the recording

Table 1. A Comparison of the Sound Distortions Regarding Different Observation Periods

	With No Retainer, (n)		Only Upper Retainer, (n)		Only Lower Retainer, (n)		Both Retainers, (n)	
Consonants	No Distortion	Distortion	No Distortion	Distortion	No Distortion	Distortion	No Distortion	Distortion
[t]	12	0	9	3	12	0	8	4
[d]	12	0	12	0	12	0	12	0
[n]	12	0	12	0	12	0	12	0
[k]	12	0	8	4	12	0	8	4
[g]	12	0	9	3	11	1	10	2
[h]	12	0	12	0	12	0	12	0
[l]	12	0	10	2	12	0	11	1
[r]	12	0	11	1	11	1	11	1
[p]	12	0	12	0	12	0	12	0
[ş]	12	0	6	6	9	3	4	8
[z]	12	0	12	0	8	4	6	6
[s]	12	0	9	3	9	3	7	5
[j]	12	0	10	2	11	1	7	5
[ç]	12	0	9	3	10	2	8	4
[y]	12	0	12	0	12	0	12	0
[c]	12	0	12	0	11	1	9	3

(n) = Number.
*** $P \leq .001$.

period, the participants were seated in an upright position and the microphone was placed 15 cm away from the participants' mouths. The subjects were instructed to produce [i, e, a, u] at a comfortable pitch and loudness. Recorded data were analyzed later by a speech-language pathologist (Figure 4).

Statistical Analysis

Analyses of the data were performed with the Statistical Package for the Social Sciences version 16.0 software (SPSS Inc, Chicago, Ill). The Cochran Q-test was performed to evaluate the differences in articulation test results with regard to different observation periods. When a statistically significant difference existed, the McNemar test was performed in order to assess the differences between the periods. The Friedman test was used to define acoustic test differences between observation periods. When a statistically significant difference was found, double comparisons were performed using the Wilcoxon test to determine which measurement was responsible for the difference. A *P* value of less than .05 was considered statistically significant.

RESULTS

Articulation Test

Statistically significant distortion was recorded only with [ş] and [z] consonant sounds ($P < .001$) (Table 1). On the first day, six of 12 patients showed distortion of the [ş] sound with the upper retainer ($P < .05$); on the other hand, when both retainers were worn, eight patients showed distortion ($P < .01$) (Table 2). At the first week, distortion of the [ş] sound was recorded in seven patients ($P < .05$). At the fourth week and third month, distortion of the [ş] sound was present in only four and three patients, respectively ($P > .05$) (Table 2).

Distortion of the [z] sound was recorded in six patients on the first day when both retainers were in the mouth ($P < .001$) (Table 1). At the first week, distortion of the [z] sound was present in only two patients ($P > .05$) and disappeared at the fourth week and third month (Table 2).

Acoustic Analysis

No statistically significant difference was found with regard to formant frequencies of the [a], [e], and [u] sounds. However, statistically significant differences were recorded for the [i] sound with regard to the F1, F2, and F3 frequencies ($P < .05$, $P < .01$, $P < .01$) (Table 3).

For the [i] sound, F1 frequency was recorded as 351.06 Hz with no retainer and increased to 387.90 Hz ($P < .05$) when both retainers were worn. At the first week, the F1 frequency was reduced to 379.39 Hz ($P < .01$), a value that was also statistically significantly different from the value obtained when no retainer was worn (Table 4).

The F2 frequency was recorded as 2601.60 Hz with no retainer and was reduced to 2448.40 Hz ($P < .05$) when both retainers were worn and to 2487.60 Hz at the fourth week ($P < .05$) (Table 4).

The F3 frequency was recorded as 3521.00 Hz with no retainer and was reduced to 3330.80 Hz ($P < .05$) when only the upper retainer was worn. When both retainers were in the mouth the F3 frequency was

Table 1. Extended

1 Week Later, (n)		4 Weeks Later, (n)		3 Months Later, (n)			
No Distortion	Distortion	No Distortion	Distortion	No Distortion	Distortion	Cochran's Q	*P*
11	1	12	0	11	1	13.500	.056
12	0	12	0	12	0	–	–
12	0	12	0	12	0	–	–
11	1	11	1	12	0	15.333	.180
11	1	12	0	12	0	12.000	.062
12	0	12	0	12	0	–	–
12	0	12	0	12	0	9.750	.136
12	0	12	0	12	0	4.000	.677
12	0	12	0	12	0	–	–
5	7	8	4	9	3	24.000	.001***
10	2	12	0	12	0	24.800	.001***
10	2	10	2	10	2	11.077	.086
10	2	11	1	11	1	14.087	.059
11	1	12	0	10	2	10.071	.122
12	0	12	0	12	0	–	–
12	0	12	0	10	2	12.400	.540

reduced to 3344.50 Hz ($P < .05$) and to 3289.40 Hz ($P < .01$) after 4 weeks (Table 4).

DISCUSSION

To summarize the significant findings of our study, it is well known that oral appliances can cause differences in speech production, usually affecting tongue posture and palatal volume. Haydar et al.[9] used the horseshoe-type retainers and found that the most prominent distortions were observed on the first day with the [t] and [d] consonant sounds when only the upper retainer was worn; they also noted [k] consonant sound distortion when both retainers were worn. They also stated that the [ş] and [z] consonant sounds appeared to be slightly distorted without retainers, so wearing retainers did not seem to cause any apparent distortions. However, in our study, the inclusion criteria were no articulation errors before wearing retainers; [ş] and [z] consonant sounds were found to be distorted after retainer wear. In addition, the fricatives are made with continuous noise production. The intensity of the noise varies with the location of articulation. The lingua-alveolar fricatives [s, z] are among the most intense. Fricative consonants are formed by a narrow constriction, through which air flow is channeled, and as the air flows through the narrow opening, a continuous frication noise is generated. However, with the stop consonants, such as [t, d], the oral cavity is completely closed at some point for a brief interval, and upon release of the stop closure, a burst of noise typically is heard. Although both stops ([t, d]) and fricatives ([ş] and [z]) can have associated noise segments, the noise burst segment for stops (10 to 20 ms) is much briefer than for fricatives (approximately 100 ms).[15] Therefore, backing of the tongue leads to sound distortions as the place of articulation changes.

Despite the fact that removable appliances are less uncomfortable than fixed appliances, they disturb

Table 2. Statistical Evaluation of the [ş]and [z] Sound Distortions in the Different Observations

	With No Retainer	Only Lower Retainer	Both Retainers	1 Week Later	4 Weeks Later	3 Months Later
[ş] sound						
Only upper retainer	0.031*	0.250	0.625	1.000	0.625	0.375
Only lower retainer	0.250	*****	0.062	0.125	1.000	1.000
Both retainers	0.008**	0.062	*****	1.000	0.125	0.062
1 week later	0.016*	0.125	1.000	*****	0.250	0.125
4 weeks later	0.125	1.000	0.125	0.250	*****	1.000
[z] sound						
Only upper retainer	*****	0.125	0.625	0.500	*****	*****
Only lower retainer	0.125	*****	0.625	0.219	0.125	0.125
Both retainers	0.036*	0.625	*****	0.219	0.036*	0.036*
1 week later	0.500	0.219	0.219	*****	0.500	0.500
4 weeks later	*****	0.125	0.036*	0.500	*****	*****

* $P \leq .05$; ** $P \leq .01$; ***** Same value.

Table 3. A Comparison of the Acoustic Test (in Hz) Differences Between Observation Periods of the Four Vowels [e, a, i, u]

	With No Retainer		Only Lower Retainer		Only Upper Retainer		Both Retainers		1 Week Later		4 Weeks Later		3 Months Later		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P
[e]															
F1	573.82	107.74	588.21	99.15	592.91	120.29	572.55	135.66	626.63	168.83	584.34	125.72	588.33	102.84	.076
F2	2327.20	207.23	2302.70	188.03	2278.70	245.04	2260.30	212.41	2296.50	188.43	2299.20	234.95	2272.40	197.21	.160
F3	3226.90	285.76	3144.60	254.08	3179.40	305.70	3143.30	215.41	3275.50	323.73	3264.00	353.81	3204.90	263.08	.373
[a]															
F1	853.16	103.71	841.12	88.47	829.92	101.17	851.41	94.05	851.92	98.40	854.70	104.36	863.64	128.43	.822
F2	1417.00	200.47	1429.10	179.75	1421.20	171.09	1423.20	224.10	1431.10	237.11	1462.50	309.52	1509.80	251.97	.530
F3	3114.90	187.08	3263.30	178.81	3226.20	279.09	3179.20	312.37	3176.70	209.38	3194.50	269.07	3281.10	206.84	.341
[i]															
F1	351.06	50.97	361.47	62.74	364.27	70.95	387.90	74.23	379.39	63.83	367.49	58.08	370.69	66.12	.045*
F2	2601.60	286.36	2534.30	233.74	2459.60	206.47	2448.40	265.62	2515.20	238.27	2487.60	231.70	2577.60	243.82	.004**
F3	3521.00	310.47	3452.10	318.11	3330.80	333.13	3344.50	356.31	3473.30	338.99	3289.40	291.65	3374.10	294.05	.007**
[u]															
F1	396.48	65.34	394.58	72.00	400.95	90.02	395.07	60.10	411.23	72.48	387.38	86.63	389.26	70.93	.407
F2	1193.20	421.39	1170.00	413.24	1047.30	194.66	1121.80	415.24	1078.50	218.87	991.13	197.78	1138.70	403.82	.512
F3	3112.50	357.35	3248.50	372.45	3046.80	235.83	3202.40	391.32	3066.20	208.71	3053.10	339.62	3102.40	363.57	.204

[a] SD indicates standard deviation; F1, first formant frequency; F2, second formant frequency; and F3, third formant frequency.
* $P \leq .05$; ** $P \leq .01$.

speech.[11] The thickness of the retainers is an important factor in the adaptation period; the thinner the appliance, the shorter the adaptation. Flege[28] assessed listener ranking and reported that appliances that were designed to be 0.5 mm thick had no negative effect on the speech production. Erb[8] showed that a thin retainer with roughening in the anterior alveolar area caused the fewest speech problems and that most of the patients showed an adaptation to their retainers within 2 weeks. In our study, we found that the first week is the critical period for the adaptation, which is in agreement with the findings of Stewart et al.[11]

As the vocal tract changes in shape and length, its resonance frequencies change and the vowel quality therefore changes.[15] Maxillary and mandibular retainers may decrease the dimensions of the oral cavity, thus changing the vocal tract and, thus, the intelligibility of speech.

F1 is primarily related to the articulatory feature of tongue height. In other words, the vowels with a low tongue position have a high F1 value, whereas vowels with a high tongue position have a lower F1 value.[15] On the other hand, F2 frequency generally is related to the feature of tongue advancement. Vowels with a back tongue position have a low F2 value, whereas vowels with a front tongue position have a high F2 value when either the front half of the vocal tract (the mouth) and the back half (the pharynx) are narrowed in relation to the other half or when a front constriction (eg, raising the tongue toward the roof of the mouth, as in the vowel [i]) lowers the F1 and raises the F2. This creates a more diffuse sound across the frequency spectrum. On the other hand, a back constriction raises the F1 and lowers the F2, making the overall sound more compact in the middle part of the frequency spectrum, as in the case of an [a] vowel. A constriction in the center of the vocal tract, as in [u], does not affect the formant frequencies, but the large degree of lip rounding lowers both the first and second formants for [u].[29]

In the present study, the effect of the Hawley appliance on speech clarity was studied objectively for the first time. According to our results, the F1

Table 4. Statistical Evaluation of the First, Second, and Third Formant Frequencies (F1, F2, and F3, respectively; in Hz) of the [i] Sound in the Different Observation Periods

[i]	Only Upper Retainer	Only Lower Retainer	Both Retainers	1 Week Later	4 Weeks Later	3 Months Later
F1	0.530	0.530	0.023*	0.002**	0.182	0.136
F2	0.041*	0.099	0.028*	0.084	0.028*	0.239
F3	0.019*	0.388	0.041*	0.433	0.005**	0.084

* $P \leq .05$; ** $P \leq .01$.

frequency of [i] is increased and the F2 frequency of [i] is decreased. [i] is a high front vowel. The predominant articulation error is backed and lowered articulation. The place of articulation is realized posterior to the target place. However, it is not perceptually deviant, because backed oral productions have a lesser impact on speech intelligibility and acceptability. We can conclude that changes in the anterior portion of the mouth can affect the articulation manner of the high front vowels.

In our study, with regard to the [i] vowel, when both retainers were worn, F1 was increased and F2 was decreased. In addition, F3 was decreased. As all three first formants were changed when both retainers were worn, it is reasonable to say that the tongue moved to the more low and back position, affecting F1 and F2 and leading to a shorter vocal tract, which in turn affects F3.

CONCLUSIONS

- The results of this study showed that the change in the anterior oral cavity produced by the Hawley appliance causes a distortion of the [ş] and [z] sounds as well as the [i] sound relating to formant frequencies.
- We can conclude that the retainer causes temporary changes in speech, as the patients can adapt their speech patterns to the retainer. However, this adaptation period can last for 1 week or for as long as 3 months.

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