Effects of Minerva Orthosis on Larynx Height in Young, Healthy Volunteers

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ABSTRACT

BACKGROUND: During speech, larynx is higher in the neck for high-pitched sounds and lower for low-pitched sounds. Patients with different problems in cervical and cervicothoracic spine use cervical orthosis to limit cervical motion. This study aimed to evaluate the effects of Minerva orthosis on larynx height in young, healthy volunteers.

SUBJECTS AND METHODS: This study included 18 subjects. Acoustic measurement of frequency variability has been assessed in 3 brace conditions: (1) without brace, (2) with brace, and (3) 30 minutes after wearing the brace.

RESULTS: Several statistically significant differences were found in the comparison between Minerva and 30 minutes after Minerva.

CONCLUSION: When planning cervical orthosis treatment, it is important to consider the reduction in larynx height that may result from bracing for those who are already at risk of developing dysphagia and dysphonia.

KEYWORDS: Standard Minerva orthosis, larynx height, fundamental frequency variability

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Introduction

One of the important elements of social interaction in everyday life is voice. The mechanism of voice production is complex. In fact, due to different linguistic and communicative demands, people vary the pitch of their voice to signal linguistic information.[1] Speakers have to change their pitch to appropriately convey their message.[2] Vocal variability is the amount of variation observed in a voice sample. These variations can be acoustically measured in hertz by examining the amount of change in the fundamental frequency (F0) of a speech segment.[3]

It is well supported that in sustained phonation, larynx height (vertical laryngeal position) tends to be relevant to the voice fundamental frequency. During speaking, the larynx moves up and down as the F0 rises and falls. Therefore, a critical factor of F0 control mechanisms is the vertical movement of the larynx.[4] The phenomenon of vertical motion of the larynx in F0 changes has been well known using optical instruments,[5,6] mechanical instruments,[7] radiography devices, and magnetic resonance imaging.[8–10]

Vertical laryngeal movement takes place along the cervical spine, which demonstrates lordosis at the level of the larynx. The cricoid cartilage rotates as it moves up and down along the cervical lordosis. Laryngeal extrinsic muscles should be able to raise and lower at the neck, and that this motion contributes to vocal frequency variation is a direct acoustic result of this motion.[4] The larynx is considerably lower directly after the end of falling-pitch vowels, compared with rising-pitch vowels. This means that the larynx is higher in the throat for high-pitched sounds and lower for low-pitched sounds.[11]

Patients with different problems in the cervical and cervicothoracic spine use a cervical orthosis.[12,13] The importance of cervical orthosis is normally based on its capability to limit cervical motion while maximizing patient comfort and minimizing negative impact on the individual's daily functions. However, common side effects can occur while wearing the collars, which may result in a reduction in effectiveness for the patient. Patients usually complain of general discomfort issues, and sometimes they may suffer from more serious side effects such as pressure sores, increased intracranial pressure, dysphagia, abnormal distraction within the upper spine, and limitation of oral and laryngeal mobility.[14]

Several studies examined the relationship between swallowing and the cervical spine in a number of contexts, including dysphagia in patients with cervical spine lesions,[15–17] postoperative dysphagia after cervical spinal surgery,[18,19] and cervical spinal positioning during deglutition.[20] In general, movement of the entire cervical spine required during normal swallowing was disturbed when the cervical spine motions are restricted. Although dysphagia is a multifactorial problem, literature analysis of dysphagia after cervical spine surgery indicates that a reduction in cervical spine movement and restriction of the chin-down posture can be risk factors for dysphagia.[21]

Some studies have examined the effect of cervical collars on laryngeal movement during the conditions of swallowing. The literature suggests that wearing a cervical orthosis can alter both swallowing mechanism (anatomy) and function (physiology) in adults without any known risk factors for developing dysphagia.[22–24]

Currently, many people need to use a rigid cervical collar every year. Although the role of the standard rigid collar is to stabilize the cervical spine, it is possible that it limits the movements of the larynx in the neck during speaking. Cervical collar may limit larynx height due to restricted movements of the larynx through generating a different range of frequencies. Due to reduced F0 variability, the speaker may not be able to adjust phonation correctly while speaking. Over time, resistance to laryngeal displacement could contribute to onset of dysphonia. Reduced frequency range and abnormal pitch are frequent negative voice effects of dysphonia and can be associated with phonotraumatic behavior. Therefore, laryngeal height may be a critical and very interesting parameter for the clinical and therapeutic variable to address in the management of dysphonic patients because the position of larynx in the cervical spine plays a significant role in maximizing the capacity of the vocal functions.[25] At present, there are no studies evaluating the effects of cervical bracing on vocal functions in normal individuals. The aim of this study is to analyze the effects of Minerva orthosis on pitch flexibility. It is important to determine the potential effects of cervical orthosis on pitch features because this knowledge is imperative for making decisions about bracing and modifications during speaking, especially for those who are already at risk of developing dysphagia and dysphonia.

Method

Participant

Thirty healthy adult volunteers aged between 18 and 28 years were recruited from university staff, 18 of whom (9 female adults and 9 male adults) were randomly selected. Prior to data collection, all participants signed an ethical consent form, confirmed by Faculty of Rehabilitation at Isfahan University of Medical Sciences. All the participants were native Persian speakers, who self-reported not having speech, language, hearing, respiratory deficits or any other sensory/motor deficits. Subjects did not show evidence of any voice-altering conditions such as an upper respiratory infection or allergies at the time of testing.

Parameters

Acoustic measures of average fundamental frequency (F0) and range of F0 in isolated vowels and speaking fundamental frequency (SFF) in connected speech were selected as standard objective parameters which have been frequently used in prior studies (Table 1).[26]

Table 1. F0 measures calculated.

MEASURE	ABBREVIATION	UNIT
Maximum fundamental frequency	F0 Max	HZ
Minimum fundamental frequency	F0 Min	HZ
Maximum phonational frequency range	MPFR	ST
Minimum speaking fundamental frequency	Min SFF	HZ
Maximum speaking fundamental frequency	Max SFF	HZ
Speaking fundamental frequency range	SFF range	ST
Pitch sigma	SFF SD	ST

Standard Minerva cervical orthosis

Minerva orthosis is a molded orthosis which restricts the motions of cervical and cervicothoracic regions. It extends from the upper part of the head (occiput) to the lower part of the thoracic region (T12). The orthoses used in this study were manufactured in technical orthopedics clinic of Isfahan University of Medical Sciences in conformity with the AAOS book (Figure 1).[27]

Acoustic analysis

After a short training period to familiarize each participant with the experimental tasks, each participant was asked to perform the following tasks;

F0 variability. To determine the speakers' individual F0 ranges, we used a common method for clinical or experimental purposes whereby speakers produced rising or falling spoken glissandos during the vowel/ a/. Participants phonated the vowel at a comfortable, normal pitch, and then they increased pitch gradually (but quickly) higher until they felt their voice break. Falling sweeps were instructed and recorded in the same way.[26,28] We elicited samples which had no creaky voice, but falsetto voices were retained.[27,29] Then the frequency values were identified via inspection of F0 tracks that were made employing the autocorrelation method in Praat (version 5.0.32).[29]

Speaking F0 variability. To be consistent with previous studies, a reading of the Rainbow passage was also elicited from each speaker. Speakers first read this passage silently to be familiarized with it before reading it aloud to be recorded at

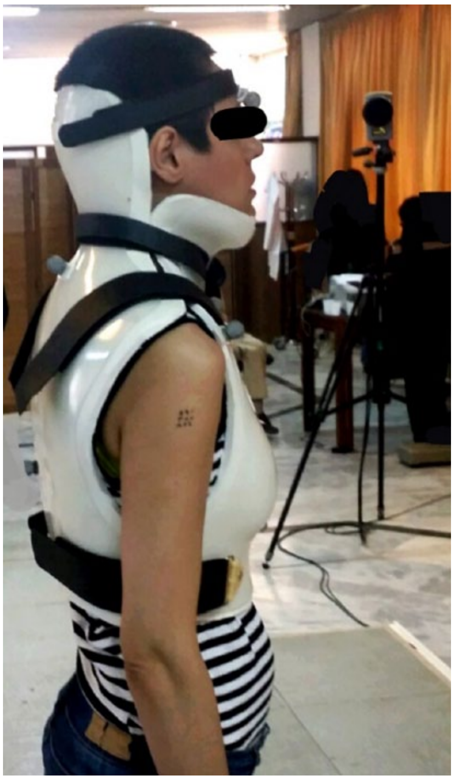

Figure1. The Minerva cervical orthosis.

Figure 2. The 7 infrared cameras in Musculoskeletal Research Center.

a normal speech rate. As only voiced parts were required for F0 analysis, silent and voiceless parts of each speech sample were removed manually with the remaining voiced-only portions analyzed using Praat software. Analysis of the waveforms and spectrograms was performed by 2 expert speech-language pathologists independently. To determine the consistency of the analysis methods, intraclass correlation coefficient (ICC) was calculated to show inter-rater and intrarater reliability. After speech sample editing was completed, frequency values were determined by the autocorrelation method in Praat.[30]

Recording procedure. To provide verification of suitability of Minerva orthosis, before acoustic evaluation, a motion analysis system with 7 high-speed cameras was used to record the motions of upper cervical (occiput), cervical, and cervicothoracic regions (Figure 2).

Two technical orthopedics students conducted the experimental procedure at the Musculoskeletal Research Center in Isfahan University of Medical Sciences. One of both positioned markers on important skeletal landmarks and explained the tasks and how to perform the task-related movements to subjects. The other student recorded the data with cameras and QTM software (version 7.5; the Qualisys, Göteborg, Sweden). Seven infrared cameras recorded data in 3 dimensions and analyzed the motions together with the QTM software. The data were collected with a frequency of 120 Hz and filtered with a cutoff frequency of 10 Hz (Figure 3). Each subject performed all the task-related movements (flexion/extension, right and left lateral bending, right and left rotation) without vocalization. The head and neck were in a static position for 3 seconds and then the test was repeated to collect 3 repetitions for each motion. The mean value of 3 repetitions was obtained for each motion.

A digital audio recorder (Edirol/Roland R-44) was used to record speech samples with a sampling frequency of 44 100 Hz and a 24-bit quantization rate. During the recording, the microphone was located at a 45° angle on the horizontal axis and 10 cm away from the speaker's mouth. All voice recordings and samples were obtained in the Speech and Voice Laboratory at the Isfahan University of Medical Sciences. This room exhibits less than 10 dB sound pressure level (SPL) of ambient noise. Data collection was conducted under 3 conditions:

1. Without the Minerva orthosis (–M);
2. With Minerva orthosis (+M);
3. 30 minutes after wearing Minerva orthosis (30 minutes +M)

Statistical analysis. Finally, we entered the collected data into SPSS software (version 20), which was used for all statistical analyses. Normality of distribution of variables was confirmed using the Kolmogorov-Smirnov test and by confirming data normality. Repeated-measures analysis of variance was used to assess changes in mean variables over time, starting from before wearing orthosis to 30 minutes after that. Level of significance was considered to be less than .05. As a post hoc test, we used paired sample *t*-test to compare the mean variables of the study in two-by-two comparisons of 3 conditions

Result

Inter-rater and intrarater reliability were calculated by examining the reliability of voice edition. The ICC was $P1 = .97$ for inter-rater reliability and $P2 = .986$ for intrarater reliability, which indicates stability and reliability of voice edition.

Minerva cervical orthosis

The mean values of motions of the upper cervical region (occiput relative to C7) with or without Minerva orthosis are shown in Table 2. The mean values of flexion range of motion

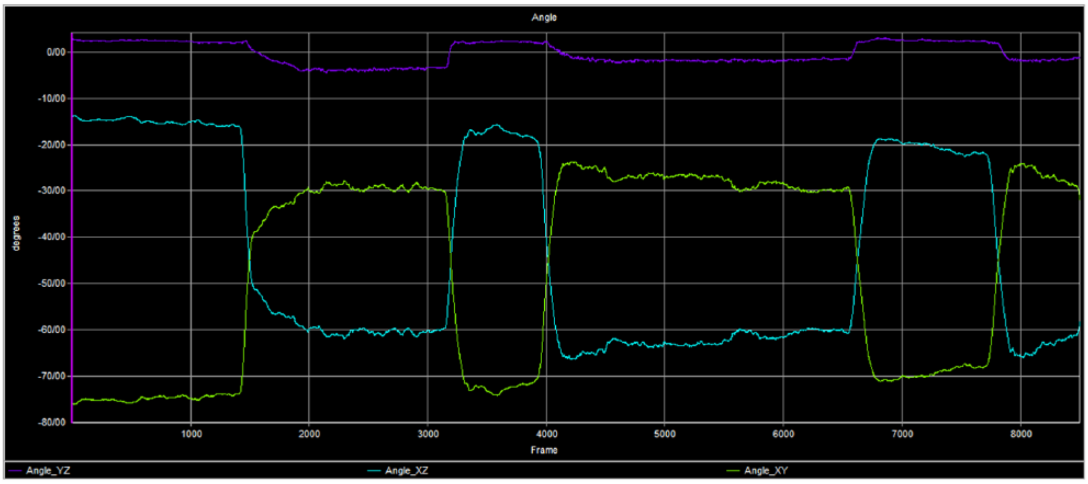

Figure 3. The angles (flexion/extension = XZ, lateral bending = YZ, and rotation = XY).

Table 2. Mean of ROM of all main and side movements in the region of the occiput and the spinous process of vertebra C7 (Oxi to C7).

MOVEMENTS	CONDITIONS	
	WITH ORTHOSIS	WITHOUT ORTHOSIS
Flexion (main motion)	4.05	43.45
Rotation (side motion)	2.20	23.60
Lateral bending (side motion)	0.0	0.70
Extension (main motion)	5.25	44.20
Rotation (side motion)	3.45	37.95
Lateral bending (side motion)	0.05	2.10
Lateral bending (main motion)	2.92	21.05
Flexion-Extension (side motion)	1.17	5.72
Rotation (side motion)	1.32	14.50
Rotation (main motion)	3.22	22.70
Flexion-Extension (side motion)	0.55	22.15
Lateral bending (side motion)	1	27.67

Abbreviation: ROM, range of motion.

Table 3. Average percent restriction of ROM compared with the no orthosis main and side movements in the region of the occiput and the spinous process of vertebra C7 (Oxi to C7).

MOVEMENTS	CONDITION
	AVERAGE PERCENT RESTRICTION OF ROM
Flexion (main motion)	90.67
Rotation (side motion)	90.67
Lateral bending (side motion)	100
Extension (main motion)	88.12
Rotation (side motion)	90.90
Lateral bending (side motion)	97.61
Lateral bending (main motion)	86.32
Flexion-Extension (side motion)	80.77
Rotation (side motion)	89.59
Rotation (main motion)	85.94
Flexion-Extension (side motion)	97.21
Lateral bending (side motion)	96.38

Abbreviation: ROM, range of motion.

decreased by more than 90% (43.45° without an orthosis compared with 4.05° with orthosis). In contrast, extension decreased by 88.12% while using Minerva orthosis. The lateral bending to right and left decreased by more than 86.32% following the use of orthosis (Table 3). The results showed that Minerva orthosis provides a high degree of immobilization.

Acoustic analysis

Repeated-measures analysis of variance showed that in male speakers, mean of F0 Min, maximum phonational frequency range (MPFR), and minimum speaking fundamental frequency (Min SFF) had significant changes over time (–M to 30 minutes +M) with a value of $P < .05$. Table 4 shows an increase in the mean of F0 Min and Min SFF and a decrease in the mean of MPFR over time.

Table 4. Comparison of acoustic measures in male speakers.

VARIABLES	CONDITIONS						
	–M	+M	30 MINUTES +M	*P*-VALUE			
				P1	*P2*	*P3*	*P4*
F0 Min	88.71 ± 20.29	92.17 ± 18.37	135.37 ± 20.56	<.001	.383	.001	.001
F0 Max	444.65 ± 88.46	428.69 ± 85.60	394.68 ± 70.65	.112	.455	.022	.239
MPFR	22.93 ± 2.65	22.63 ± 3.45	19.66 ± 1.41	.010	.508	.003	.025
Min SFF	87.41 ± 13.15	89.30 ± 13.00	122.96 ± 14.24	<.001	.604	<.001	.001
Max SFF	332.33 ± 59.16	328.57 ± 23.86	317.16 ± 35.23	.487	.824	.224	.360
SFF range	14.62 ± 4.18	14.19 ± 3.60	13.90 ± 4.01	.232	.444	.001	.500
Pitch sigma	2.58 ± 0.83	2.32 ± 0.86	2.19 ± 0.69	.074	.185	.003	.509

Abbreviations: F0 Min, minimum fundamental frequency; F0 Max, maximum fundamental frequency; MPFR, maximum phonational frequency range; Min SFF, minimum speaking fundamental frequency; Max SFF, maximum speaking fundamental frequency; SFF range, speaking fundamental frequency range.
P1, the significance level of the variance analysis test in repeat measure to compare the mean of each variable over time (starting from –M to 30 minutes +M); P2, the significance level of the paired sample *t*-test to compare the mean of each variable in –M and +M conditions; P3, the significance level of the paired sample *t*-test to compare the mean of each variable in –M and 30 minutes +M conditions; P4, the significance level of the paired sample *t*-test to compare the mean of each variable in +M and 30 minutes +M conditions.

For female speakers, the repeated-measures analysis of variance showed that mean of F0 max, MPFR, and Min SFF had significant changes over time (–M to 30 minutes +M) with a value of $P < .05$, in a way that the mean of F0 max and MPFR decreased and against that the mean of Min SFF had a significant increase over time (Table 5).

Results of vocal variability (MPFR, SFF range, and pitch sigma) in 3 conditions showed that speakers demonstrated less pitch variation in 30 minutes +M condition compared with –M and+ M conditions (Figures 4 and 5).

The post hoc paired *t*-test revealed that there were a significant difference between the –M and 30 minutes +M conditions ($P < .05$). Significant parameters between 2 conditions were F0 Min, MPFR, Min SFF, maximum speaking fundamental frequency (Max SFF), SFF range, and pitch sigma in males and F0 Min, F0 max, MPFR, and Min SFF in females (Tables 4 and 5).

Discussion

The aim of this study was to investigate the effect of the use of a Minerva orthosis on fundamental frequency variability in 18 young healthy Volunteers. The results indicated that there were no statistically significant differences between frequency parameters in –M and +M conditions. However, the following statistically significant differences in parameters were observed in the comparison of the 30 minutes +M to –M conditions: reduced MPFR in males and females, increased minimum F0 in males, reduced maximum frequency in females, and increased minimum SFF in males and females. Furthermore, the 30 minutes +M condition appeared to have the greatest impact on SFF range and pitch sigma.

In the high F0 range, forward movement of the hyoid bone is produced by the action of the suprahyoid articulatory muscles such as genioglossus and geniohyoid muscles and facilitates rotation of the thyroid cartilage for raising F0, so in the high F0 range, the jaw and hyoid bone move slightly backward and the vertical laryngeal movement is relatively minor.[4,25]

In the low F0 range, the larynx lowering is mainly due to the contraction of the infrahyoid extrinsic laryngeal muscles. This action induces rotation of the cricoid cartilage along the cervical lordosis. In the low F0, the jaw opens and hyoid bone moves backward and then downward. In general, for low F0 range, all of the structures of the jaw, hyoid bone, and the laryngeal cartilages show a large downward movement.[4,25] The results of this study indicate that the minimum frequency increased 30 minutes after wearing Minerva orthosis in both tasks (sustained vowel and text reading) and in both sexes. However, for women, a significant decrease in maximum frequency only occurred in sustained vowel task in women. In the high F0 range, horizontal movement of the hyoid bone can be consistently observed and vertical laryngeal movement is relatively small. In the low F0 range, a large vertical movement of the hyoid-larynx complex is observed along the cervical spine.[4] Therefore, Minerva orthosis has more impact on the lower larynx position and progressive downward movements of the hyoid bone and larynx. These conditions are accompanied by a reduction in vocal variation.

Based on the theories of speech production, the fundamental frequency is also affected by other factors. An important hypothesis in the process of speech production is the source-filter theory which splits the speech production system into 2 major parts: voice source (larynx) and filter (resonators). Speech

Table 5. Comparison of acoustic measures in female speakers.

VARIABLES	CONDITIONS						
	–M	+M	30 MINUTES +M	*P*-VALUE			
				*P*1	*P*2	*P*3	*P*4
F0 Min	163.37 ± 28.67	169.86 ± 32.06	185.18 ± 14.69	.167	.144	.093	.293
F0 Max	693.62 ± 215.32	647.65 ± 247.18	425.77 ± 78.05	.002	.288	.005	.025
MPFR	28.62 ± 5.76	27.73 ± 4.95	20.42 ± 2.50	<.001	.444	.002	.003
Min SFF	87.41 ± 13.15	142.35 ± 31.21	182.06 ± 30.41	<.001	.214	<.001	.004
Max SFF	440.22±119.15	431.07 ± 99.29	365.44 ± 101.23	.174	.715	.150	.178
SFF range	16.42 ± 4.39	15.56 ± 3.56	14.44 ± 4.02	.313	.274	.244	.417
Pitch sigma	2.78 ± 0.75	2.61 ± 0.57	2.44 ± 0.75	.119	.174	.136	.425

Abbreviations: F0 Min, minimum fundamental frequency; F0 Max, maximum fundamental frequency; Min SFF, minimum speaking fundamental frequency; Max SFF, maximum speaking fundamental frequency; MPFR, maximum phonational frequency range; SFF range, speaking fundamental frequency range.
P1, the significance level of the variance analysis test in repeat measure to compare the mean of each variable over time (starting from –M to 30 minutes +M); P2, the significance level of the paired sample *t*-test to compare the mean of each variable in –M and +M conditions; P3, the significance level of the paired sample *t*-test to compare the mean of each variable in –M and 30 minutes +M conditions; P4, the significance level of the paired sample *t*-test to compare the mean of each variable in +M and 30 minutes +M conditions.

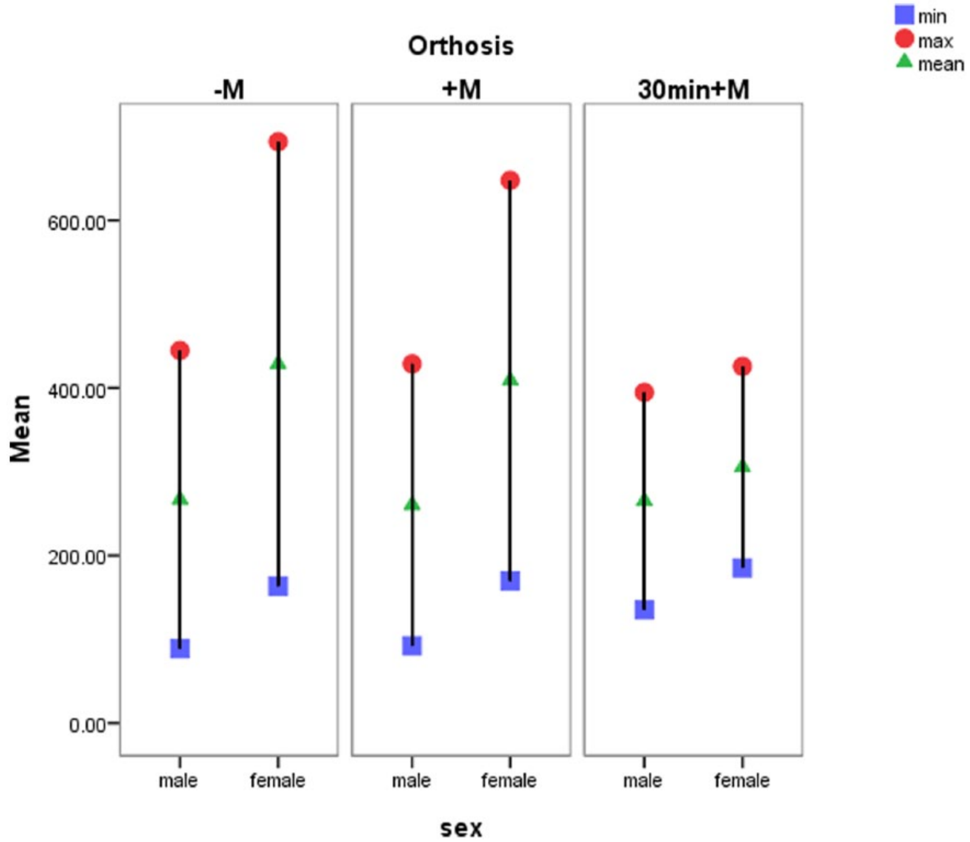

Figure 4. Mean F0 Min (from falling sweeps), mean F0 Max (from rising sweeps), and mean range (MeanMax – MeanMin) in speakers. F0 Min indicates minimum fundamental frequency; F0 Max, maximum fundamental frequency.

sounds are produced following the combination of the function of the filter and the voice source. The voice signal produced by the source passes through the vocal tract which acts as a filter and finally gets out of the mouth or nose. In fact, source and filter are interdependent.[31,32]

One of the elements of the vocal tract which is able to control fundamental frequency is jaw opening.[33] The soft tissue connections exist between the jaw-hyoid and the hyoid-larynx, and these connections cause a mandible-larynx interaction in speech articulation.[34] The magnitude of jaw opening is related

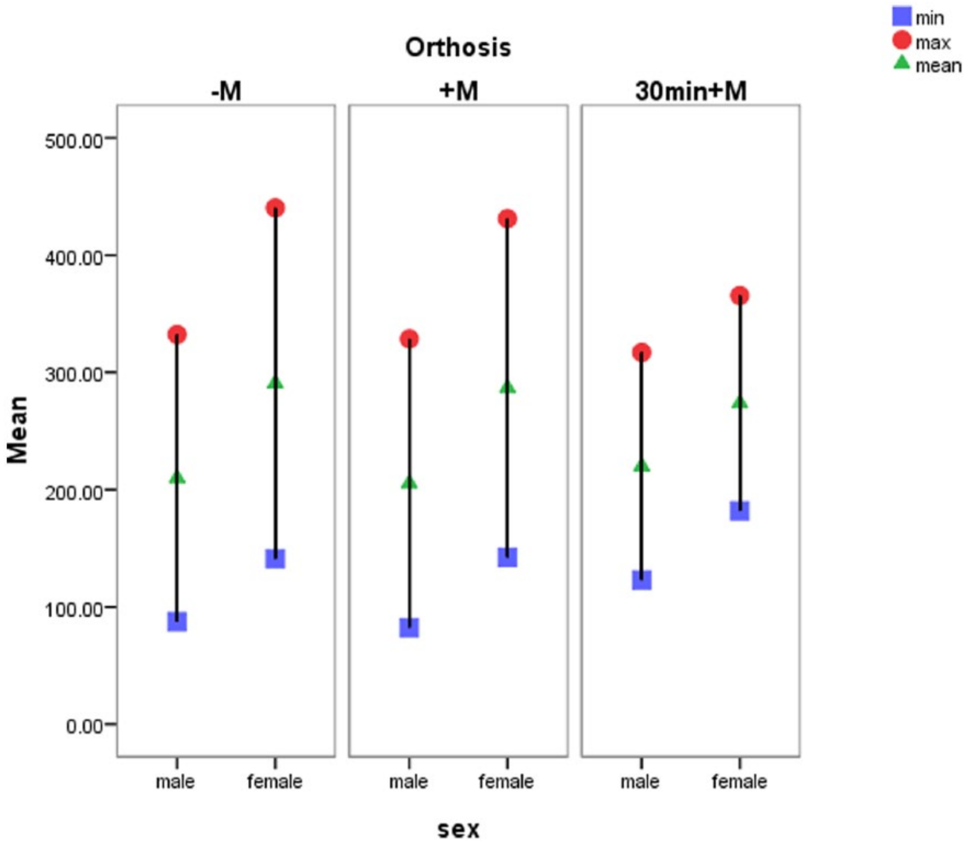

Figure 5. Mean Min SFF, mean Max SFF, and mean range (MeanMax–MeanMin) in this study. Min SFF indicates minimum speaking fundamental frequency; Max SFF, maximum speaking fundamental frequency.

to F0 and that jaw opening can control signal to achieve a higher degree of naturalness in voice.[35] Several studies of speech have reported that jaw movement may influence the F0 of larynx signal to improve the voice source simulation. Lim et al[35] found that the magnitude of jaw opening was significantly different among the 3 clusters of vowels—/u/, /i, e, o/, and /a/. These achievements suggest that 3 values of F0 can be selected for 3 ranges of magnitude of jaw opening: high F0 for small jaw movement (/u/, /i/), moderate F0 for moderate jaw movement (/e/), and low F0 for large jaw movement (/o/, /a/). Considering Minerva orthosis, the jacket extends so high to below the jaw; it can interfere with the movement of the jaw. In other words, the Minerva orthosis has mandibular support, which resists jaw movement. According to the biomechanical interaction between the articulatory and phonatory organs,[34] the magnitude of jaw opening is related inversely to F0.[34] In the high F0 range, the jaw moves slightly backward, and in the low F0 range, the jaw shows a large downward displacement. Therefore, it is expected that due to orthosis, limitation of jaw movements has more impact on the low frequency range. In this study, the effect of prolonged usage of orthosis was observed too, which has had more impact on a low frequency range as well as vocal variability.

According to data achieved from this study, the standard Minerva can limit the movements of the articulators and the larynx height when producing a different frequency range after an extended period of usage. The impact of these restrictions will be determined by the reduction of the frequency range after using orthosis. These data are consistent with the swallowing literature which proposed that cervical bracing alone could change the swallowing mechanics in healthy adults by limiting oral range of motion and restricting movement of the larynx and hyoid bone during swallowing.[22–24,36]

Laryngeal movements control different processes. Physiologically, raised larynx is strongly related to the swallowing process, working as a sphincter valve and as a mechanism for airway protection.[37,38] Laryngeal lowering is associated with inspiration and glottic opening, possibly including an abductor component in the laryngeal lowering movement.[38]All the processes mentioned above can be affected by restrictions on the laryngeal movements.

In addition, communication performance will be affected by a reduction in pitch flexibility. A number of papers have studied the role of F0 variability, which is considered to be an important criterion in the intelligibility of speech. These studies have found that F0 variation is critical for intelligibility of speech.[39,40] Given that wearing an orthosis for so long can affect the frequency range, a person who requires a cervical orthosis may be limited in production of intelligible speech over an extended period of usage, which may affect a person's ability to communicate effectively.

Conclusions

This study revealed that Minerva orthosis can have an impact on the fundamental frequency variability in young and healthy people. As the larynx height is one way that speakers can alter their F0, we conclude that reduction in larynx motion is the cause to create restrictions on frequency variations in the case of long-term use of cervical orthosis (minimum 30 minutes). Furthermore, another factor that decreases the vocal performance is the reduction in the openness of the jaw as a result of prolonged usage of orthosis. Therefore, people may experience many challenges to communicate effectively when a cervical orthosis is required to be worn for an extended period of time. When planning cervical orthosis treatment, it is important to consider the reduction in larynx height that may result from bracing for those who are already at risk of developing dysphagia and dysphonia. A need exists, particularly for who are at risk of developing dysphagia and dysphonia, to create a personalized cervical collar that prevents unwanted side effects, conforms to the patient's body, and limits movement for proper healing to occur. This study provides preliminary evidence of the effect of Minerva cervical orthosis on the larynx height, but more research is needed to clarify the exact impact of neck orthosis on voice performance. Future research should focus on the following issues:

1. Examining the effects of bracing for a wider range of vocal parameters;
2. Evaluating the effects of cervical bracing on the vocal tract shape and larynx position during phonation radiographically;
3. Checking the vocal parameters during 4 conditions (−M, +M, 30 minutes +M, −M);
4. Evaluating the effects of cervical bracing on patients who already have cervical spine problem.

Author Contribution

Study conception and design: MTK, FA, PSH, MG. Acquisition of data: FA, PSH, MG, SM. Analysis and interpretation of data: MTK, FA, PSH. Drafting of manuscript: MTK, FA, PSH, SM, MG. Critical revision: MTK, FA, PSH, SM.

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