

Reinforced falsetto to increase the glottic closure in patients diagnosed with unilateral vocal fold paralysis: A preliminary study

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<https://dx.doi.org/10.5209/rlog.92709>

Received November 25 th 2023 • First revision 25th January 2024 • Accepted June 13th 2024

Abstract: There is favourable evidence in speech therapy for the rehabilitation of vocal fold paralysis. Nonetheless, contemporaneous studies that apply reinforced falsetto were not found. The aim of this study is to determine the results of speech therapy using reinforced falsetto for complete glottic closure in patients diagnosed with unilateral vocal fold paralysis, who were treated at the Laboratory of Voice at the 'Universidad del Desarrollo' in Chile between 2015 and 2023. A descriptive, observational and retrospective study was performed on 10 adult participants. Before therapy, grade of dysphonia was severe in 90% of the participants, whilst moderate in the remaining 10%. Incomplete glottic closure was observed in 100% of the participants. After the therapy, grade of dysphonia was diagnosed as being mild in 60% of the cases, and normal in the remaining 40% of participants. All the participants recovered their glottic closure. Significant differences were observed pre-intervention and post-intervention in: fundamental frequency; sound intensity; harmonics; maximum phonation time; glottic closure; and dysphonia severity. In conclusion, the reinforced falsetto technique was favourable for the glottic closure in the sample of participants studied. Further, there was clinical improvement in all the analysed acoustic and laryngoscopic variables. Speech therapy using reinforced falsetto could therefore be useful for the rehabilitation of unilateral vocal fold paralysis. It is suggested that extra research is performed, including a representative sample, in order to generalise the results and make them applicable to the general population.

Key words: Voice; Voice Disorders; Vocal Fold Paralysis; Rehabilitation.

ESP Estrategia de falsete reforzado para el aumento del cierre glótico en pacientes con parálisis de pliegue vocal unilateral: un estudio preliminar

Resumen: Existe evidencia de la terapia fonoaudiológica en pacientes con parálisis de pliegue vocal unilateral. Sin embargo, no se han encontrado estudios que analicen el uso del falsete reforzado. El objetivo de este estudio corresponde a determinar los resultados de la terapia fonoaudiológica de falsete reforzado para el aumento del cierre glótico en pacientes con parálisis de pliegue vocal unilateral que fueron atendidos en el Laboratorio de Voz de la Universidad del Desarrollo entre los años 2015 y 2023. Se realizó un estudio descriptivo, observacional y retrospectivo, que incluyó 10 sujetos mayores de edad. Previo a la terapia, el grado de severidad de la disfonía fue severa en el 90% de los casos y moderada en el 10%. El 100% presentó cierre cordal incompleto. Posterior a la terapia, el grado de severidad fue leve en el 60%, mientras que grado normal en el 40% con cierre cordal completo. Se determinó que hubo diferencia estadísticamente significativa pre y post intervención en las siguientes variables: frecuencia fundamental, intensidad vocal, armónicos, tiempo máximo de fonación, cierre cordal, y grado de severidad de la disfonía. Se concluye que, en la muestra, la estrategia de falsete reforzado fue favorable para el cierre glótico. Hubo mejora en todas las variables vocales (acústicas y laringoscópicas) analizadas, por lo que esta estrategia podría ser útil para el tratamiento de la parálisis unilateral del pliegue vocal. Se sugiere ampliar la muestra para lograr resultados generalizables a la población.

Palabras clave: Parálisis de los Pliegues Vocales; Rehabilitación; Trastornos de la Voz; Voz.

Sumario: Introduction. Method. Participants Inclusion and exclusion criteria. Instruments Variables Procedure. Data analysis. Ethics considerations. Results. Participants. Clinical information. Statistical analysis. Discussion. Glottic closure. Maximum phonation time. Voice intensity. Fundamental frequency. Harmonics. Severity of the dysphonia. Therapeutic potential of the reinforced falsetto technique in UVFP: physiological benefits and clinical considerations. Bias. Limitations. Projection. Conclusions. References.

Cómo citar: Orellana Marambio, P.; Gonzalo Rosales, F. y Monichi, G. (2024). Reinforced falsetto to increase the glottic closure in patients diagnosed with unilateral vocal fold paralysis: A preliminary study. *Revista de Investigación en Logopedia* 14(1), e92709. <https://dx.doi.org/10.5209/rlog.92709>

Introduction

Vocal folds perform a crucial role in three distinct processes: phonation, breathing and swallowing. The vagus nerve, via the recurrent laryngeal nerve (RLN) and superior laryngeal nerve (SLN), is responsible for both motor and sensory innervation of the larynx. Whilst the RLN produces the adduction and abduction of the vocal folds, the SLN produces the movements of the cricothyroid muscle. When the RLN is damaged, unilateral vocal fold paralysis (UVFP) ensues as a consequence of miss innervation (Walton et al. 2018). UVFP is a condition in which one of the vocal folds displays both lack of mobility and weakness. According to Bothe et al. (2014), the aetiology of UVFP is linked to diverse factors: neoplastic, traumatic, neurological, among others. Busto et al. (2015) include the iatrogenic factor secondary to cervical, thyroid and/or thoracic surgeries. UVFP is more frequent in the left vocal fold as the RLN is more susceptible to damage at the level of the neck, mediastinum or lungs (Bothe et al., 2014). Some authors have observed that UVFP is more prevalent in female patients, as a result of thyroid diseases which are more commonly found in women (Bothe et al., 2014; Santos et al., 2019). Moreover, thyroidectomy is the main cause of UVFP linked to surgeries (Wen y Wang, 2022). The prognosis of UVFP depends on its aetiology, in which better results are expected in UVFP arising from idiopathic and surgical damage in comparison to neoplastic causes (Bothe et al., 2014). The severity of the symptoms of UVFP will depend on the level and extent of damage and the relative position of the paralysed vocal fold. T Symptoms of UVFP could include dysphonia, aphonia, breathy voice and fatigue. Furthermore, cough, frequent expectoration, dyspnoea and dysphagia could appear in severe cases (Bothe et al., 2014; Busto et al., 2015, Santos et al., 2019). The level and extent of damage will not only depend on the lack of glottic closure, but also on any compensation done by patients to try to improve their voice quality (Santos et al., 2019).

The 'National Center for Voice and Speech' (NCVS) indicates that the assessment of the pathological voice, including UVFP, should be initiated with a spectrographic analysis, classifying each voice as either type I (or mild dysphonia), type II (or pathological voice with subharmonics and aperiodicity), or type III (or chaotic and random voice) (Droguett, 2017). For the voices type I and type II, a perceptual analysis is recommended with the addition of a spectrograph for acoustic analysis. Those procedures will determine the voice quality by considering the following acoustic parameters: fundamental frequency (F0), Jitter, Shimmer, harmonic-noise relation (HNR) and sound intensity. For the voice type III, a perceptual analysis is the sole recommendation in order to try to ascertain the vocal damage, and the relationship between the voice quality and its impact on the patient's communication skills (Farías, 2012). In relation to the acoustic parameters and the voice normative values, there are different reference to bear in mind during the analysis of pathological voices. In the case of F0, Jackson-Menaldi in 2019 determined that men have a F0 which oscillates between 98 and 165 Hz, whilst in women between 196 and 262 Hz. In Chile, the mean F0 for the vowel /a/ is 207 Hz in women and 140 in men (Díaz, Cisternas y López, 2015). For sound intensity, the mean F0 in women is 51 dB whilst in men it is 54,8 dB (Colton et al., 2011). In respect of the maximum phonation time (MPT), Zencir Sen et al. (2021) reports that the mean MPT in women is 17.53 seconds (s) for the age group between 18 to 39 years old, 16.51 s between the age group 40 and 59 years old, whilst 14.26 for women in the age group between 60 and 87 years old. In the case of men, the mean for the first, second and third age category was 22.75 s, 18.45 s and 17 s respectively. The software ANAGRAF indicates that the Jitter value is normal considering a variation lower than 1%; the Shimmer pondering up to .3 dB; and, for HNR, equal to or lower than 4 dB (Elisei, 2012). In order to assess the loss of the harmonic component of the voice, Cecconello (2012) uses the following scale:

- 0-5000 Hz: Aphonia. These are cases of non-presence of harmonic structure.
- 500-5000 Hz: Severe alteration. Exclusively presence of F0.
- 1000-5000 Hz: Moderate to severe alteration.
- 1500-5000 Hz: Moderate to severe alteration.
- 2000-5000 Hz: Moderate alteration.
- 2500-5000 Hz: Moderate alteration.
- 3000-5000 Hz: Mild to moderate alteration.
- 3500-5000 Hz: Mild alteration.
- 4000-5000 Hz: Mild alteration.
- 4500-5000 Hz: Minimal alteration.

The main therapeutic objective for the UVFP is to recover the glottic closure. Some patients who suffer from vocal fold paralysis experience spontaneous recovery, of which there are two main types: on one hand, patients in which there is spontaneous reinnervation of the nerve; and on another hand, patients compensating for the mobility of the paralysed vocal fold, using the adduction of the contralateral vocal fold (Bothe et al. 2014). Due to this, the main and first line of action consists of an observation period, in which some patients receive vocal therapy whilst other patients receive no rehabilitation (Bothe et al. 2014; Marqués et al. 2021). However, it is not always possible to recover the correct movement of the vocal fold. This is a consequence of new innervation of the laryngeal nerves (adductor and abductor muscles) which results in variable and non-selective synkinesis. Due to this, the vocal fold adopts other positions which are different to the ones prior the UVFP (Busto et al., 2016).

Patients without spontaneous recovery from UVFP are candidates for medical surgery, namely by medialisation laryngoplasty or thyroplasty, injection laryngoplasty, arytenoid adduction, and laryngeal reinnervation (Marqués et al. 2021). These techniques have the same goal in common: to achieve vocal cord medialisation. Siu et al. (2016) compared the mentioned surgical procedures and found that the use of a specific technique, or a mix of techniques, will depend on the UVFP aetiology and the presurgical laryngoscopic findings. In other words, the medical procedure and the techniques considered during the surgery must be specific to each patient and to their own vocal features and needs. Also, there is evidence which shows that early vocal therapy improves the prognosis of patients suffering from UVFP. This is due to an increase of the subglottic pressure, the improvement of glottic closure, and the self-perception of the vocal patient (Busto et al., 2015; Kaneko et al. 2020; Miyata et al. 2020; Walton et al., 2016; Walton et al., 2018). Speech and Language Therapists use diverse techniques for the rehabilitation of UVFP patients to improve their glottic function and the quality of their voice (Bothe et al. 2014). In the first instance, techniques such as laryngeal massages, postural control and speech-breathing coordination are used, with the addition of head movements to increase the glottic closure (Busto et al., 2015, Santos et al., 2019). Then, in order to induce the high pitch of the voice, the glottal fry, voice projection and the extension of the vocal range, vocal exercises are used strengthening the laryngeal sphincter (Busto et al., 2015; Jeong et al., 2020). Afterwards, semi-occluded-vocal-tract exercises are used to increase vocal resistance, along with spontaneous speaking activities, the reading of texts using 'mesa di voce', tonal variations, the use of voice intensity variations and using sing voices techniques (Santos et al, 2019). Furthermore, neuromuscular electrical stimulation, as a non-invasive technique, has reported benefits for the rehabilitation of UVFP, linked to muscle strengthening, mass maintenance, and intrinsic laryngeal muscles volume (Kurz et al., 2021). Additionally, voice therapy is recommended in patients with UVFP who are candidates for injection laryngoplasty in order to maintain their voice quality following surgery (Jeong et al. 2020). During the last years, research has demonstrated the benefits of the speech and language therapy rehabilitation for patients diagnosed with vocal cord paralysis. However, the reinforced falsetto technique has not been studied in depth for the treatment of this pathology. Empirically, Bekerman et al. (2015) have reported that the reinforced falsetto results in glottic closure.

The reinforced falsetto, as a technique used in singing voices, is performed under certain physiological features, in which the control of the laryngeal height and the elevation of the soft palate is described. When this technique is used, a greater supralaryngeal resonance area is observed in addition to less air leak, complete phase of union of the edge of the vocal folds, darker voice colour and higher voice intensity, voice projection and gradation of voice dynamics (Aguilar, 2022). In the case of countertenors, the literature describes a glottic configuration which permits exclusively the vibration of the membranous portion of the vocal folds. This is characterised by rounded lateral peaks and short laterally moving mucous waves, according to videokymographic image analyses (Herbst et al., 2009). In research performed in men and women classical singers, it is described that in the emission of a falsetto from lower to upper adduction, there is an increasement of the cartilaginous and membranous adduction of the vocal folds (Herbst et al., 2011). In sopranos, the evidence shows that the entire length of the membranous portion of the vocal folds participates in the oscillatory process during the production of high frequency tones (Echternach et al., 2013). In 2013, Kochis-Jennings et al. carried out a research project which analysed the electromyographic activity of the cricoarytenoid and thyroarytenoid muscles related to the different vocal registers. The predominant activity of the thyroarytenoid muscle was observed in the modal register and during the head/mix productions under 300 Hz. The predominant activity of the cricoarytenoid muscle was described during the ascendent glissandos in the modal register and falsetto register over 200-300 Hz. Moreover, in some participants there was a predominant activity of the cricoarytenoid muscle in modal register over 400-430 Hz, whilst other subjects had a predominant activity of the cricoarytenoid muscle in both modal and falsetto register, independently of the pitch used. Despite these results, the authors mention there is no correlation between the high predominance of the cricoarytenoid muscle activity and high pitch during the falsetto register in the sample studied. In some cases, this predominance was observed in high pitch emissions in modal register, which indicates the individual variability of the muscular activation during the phonation. For that reason, it was suggested to perform extra research of those physiological changes. In the context of vocal therapy, the reinforced falsetto is one of the facilitating sound techniques in which the emission of hyper-acute sounds allows for the relaxation of the thyroarytenoid muscle, the stretching of the vocal fold, an increase of the subglottic pressure and the contraction of the cricothyroid muscle. The use of falsetto as a therapeutic tool for UVFP is based on the possible integrity of the innervation of the cricothyroid muscle by the external portion of the superior laryngeal nerve (Ross et al., 2020). A well performed falsetto shows correct control in the contraction of the cricothyroid muscle (Cobeta et al., 2013).

In the 'Laboratory of Voice' at the 'Universidad del Desarrollo' in Chile, the speech and language therapists have observed that patients suffering from UVCP have greater facility for producing high pitch sounds, especially in the falsetto. This phenomenon could be linked to the indeminity of the superior laryngeal nerve and the activity of the cricothyroid muscle. This observation has allowed the development of a therapeutic strategy which implies breathing strategies and orofacial changing techniques to perform reinforced falsetto in order to contract the cricothyroid muscle and to achieve the medialisation of the paralysed vocal fold. After contraction of the cricothyroid muscle has been achieved, the strength of the lateral cricothyroid muscle and the interarytenoid muscle are trained in falsetto register, to descend gradually to modal register, which adds to the function of thyroarytenoid muscle. As a result, improvement of the acoustic and perceptual voice aspects and glottic closure have been observed. Due to this, since 2015 the technique has been used in the 'Laboratory of Voice' at the 'Universidad del Desarrollo' in Chile for speech and language therapists as a therapeutic alternative for patients suffering from UVFP. Quantitatively, the acoustic parameters improved in all the patients treated. For this reason, the analysis of the data collected in the 'Laboratory of Voice' is worthy to determine if the use of the reinforced falsetto was useful as a therapeutic strategy for UVFP.

The research question was developed using the PICOT strategy (Riva et al., 2012): in patients diagnosed with UVFP attended at the Laboratory of Voice at the 'Universidad del Desarrollo', Chile, between 2015 and 2023, what were the results of the speech and language therapy rehabilitation using the reinforced falsetto technique for improving the glottic closure? The objective of this project is to determine the results of speech and language therapy rehabilitation using reinforced falsetto for improving glottic closure in patients diagnosed with UVFP, and who were treated at the Laboratory of Voice at the 'Universidad del Desarrollo', Chile, between 2015 and 2023.

Method

A descriptive, observational and retrospective study was carried out.

Participants

Participants were all adult patients diagnosed with UVFP and treated using the reinforced falsetto via speech and language therapy rehabilitation between 2015 and 2023, in Santiago de Chile. A convenient and suitable sample was used as all were adult patients diagnosed with UVFP via speech and language therapy rehabilitation using the reinforced falsetto for glottic closure between 2015 and 2023 in the Laboratory of Voice at 'Universidad del Desarrollo', in Santiago de Chile.

Inclusion and exclusion criteria

Included were adult patients diagnosed with UCVP who attended the Laboratory of Voice at 'Universidad del Desarrollo' in Santiago de Chile between 2015 and 2023. The adult patients had complete registered data of the pre-therapy assessment, rehabilitation sessions and final/post-therapy assessment in the Laboratory of Voice; and each had four rehabilitation sessions as minimum. In respect of the exclusion criteria, patients with extra laryngeal pathologies were excluded.

Instruments

Database of the Laboratory of Voice of the 'Universidad del Desarrollo', Santiago de Chile; Microsoft Excel © 2016; 'Statistical Package for the Social Sciences' (SPSS) v.24, GRBAS perceptual scale (Hirano,1981), stroboscope StrobolEd brand Ecleris and code ECL- SL 103, video camera Procam brand Ecleris, laryngoscope brand Ecleris, acoustic software ANAGRAF (Gurlekian, 1997), 'Voice-Vibratory Assessment with Laryngeal Imaging' (VALI) (Poburka et., 2016), interface for sound recording brand M-Audio Fast Track Ultra, microphone brand Shure SM-58, and a Laboratory of Voice's computer.

Variables

Numeric variables were included, namely age, F0, sound intensity in decibels (dB), Jitter, Shimmer, HNR, harmonics and MPT. Further, categorical variables were included, namely dysphonia severity, dysphonia grade.

Procedure

Firstly, the main researcher accessed the database of the Laboratory of Voice at the 'Universidad del Desarrollo', which included information of the patients. They were previously evaluated by an expert Speech and Language Therapist, using a protocol of the Laboratory of Voice. The protocol included the GRBAS scale for assessing patients' sustained utterance vowel /a/ and speaking voice. The voice emissions were recorded in a silent cabin using a laptop with an M-Audio Fast Track Ultra interface, and a Shure SM58 microphone. For the acoustic analysis the ANAGRAF software was used, including the following acoustic parameters: F0, sound intensity in decibels (dB), harmonics, MPT, Jitter, Shimmer and HNR. The harmonics were assessed by the expert Speech and Language Therapist by the examination of the narrowband spectrogram given for the ANAGRAF software, using the harmonic integrity scale proposed by Cecconello (2012). Secondly, the main researcher filtered through patients to select those who fitted exclusively within the inclusion criteria. Once the patients were selected, the database was named 'Database A' protected by a password which only the main researcher had access to at the Laboratory of Voice. Afterwards, the main

researcher anonymised the 'Database A' to eliminate all possible data which could identify the patients. Thereafter, the anonymised database was saved and named 'Database B', which was protected again by password and shared with the research team for analysis. 'Database A' was then immediately deleted by the main researcher. Finally, the research team analysed the information contained in 'Database B' using SPSS.

Data analysis

Descriptive statistic and analytic statistic were used. In relation to descriptive statistic, for categorical variables, frequency and percentage were considered. For numeric variables the measures of central tendency: mean and deviation standard for parametric data, and median and interquartile range for non-parametric data. In the case of analytic statistic, a p value $< .05$ and was used. For pre- and post-intervention analysis, repeated t-test was used for symmetric data, whilst Wilcoxon was used for asymmetric data. For comparison between groups, t-test was utilised for parametric data, while Mann-Whitney for non-parametric data was used.

Ethics considerations

The project was approved on 25 of May 2023, by the Ethics Research Committee of the 'Hospital San Juan de Dios, Santiago de Chile', by the given protocol number 215.

Results

Participants

The database had information of a total of 10 patients diagnosed with UVFP in paramedian position, who fitted within the inclusion criteria. 60% of the sample were women whilst 40% were men. The mean age of the sample was 48 years old with a standard deviation of 10 years. The minimum and maximum ages were 27 and 63 respectively. The patients received therapy once a week for 50 minutes. The minimum number of sessions per patients was 4 whilst the maximum was 22 sessions. According to the harmonic component of the voice proposed by Cecconello (2012), during the initial assessment three patients presented aphonia. Due to this, it was not possible register data nor analyse MPT, FO and harmonics. Table 1 shows general information of the sample.

Clinical information

Before the speech and language therapy sessions, 90% of the sample had a severe grade of dysphonia, whilst the other 10% had a moderate grade of dysphonia. In respect of the glottic closure, 100% of the sample had an incomplete pattern. After the speech and language therapy sessions using reinforced falsetto, 60% of cases had mild dysphonia and whilst 40% had non-dysphonia. 100% of the patients had a complete glottic closure. Table 2 shows in detail the description of the categorical variables pre- and post-intervention using the reinforced falsetto technique.

In relation to the numeric variables before rehabilitation, for voice intensity the mean was 43.67 dB, for harmonics it was 1166.67 Hz and for the MPT it was 6.83 s. Further, the median of the FO was 261.50 Hz. Jitter, Shimmer and HNR could not be registered at that moment due to the level of dysphonia in the patients. Post-rehabilitation, there was an increase of the mean of voice intensity, reaching 53.80 dB; harmonics 4470.00 Hz and MPT 17 s. The mean for Jitter was 1.00; Shimmer .03; and HNR 4.42 dB. The median of the FO decrease to 189.20 Hz. Table 3 shows information of the descriptive statistic of numeric variables pre- and post-intervention using reinforced falsetto technique.

Statistical analysis

Pre- and post-intervention tests were used to analyse the data. Concerning FO, the Wilcoxon test showed there was a significant difference pre- and post-intervention using the reinforced falsetto ($z = -2.20$, $p = .028$). Nevertheless, when the comparison was applied per gender, the results were not significant. Further, the Wilcoxon test indicates that there was a significant difference pre- and post-intervention for the glottic closure ($z = -3.16$, $p = .002$), severity of the dysphonia ($z = -2.92$, $p = .004$), voice intensity ($z = -2.21$, $p = .027$), Jitter ($z = -2.80$, $p = .005$) and Shimmer ($z = -2.80$, $p = .005$). For HNR, harmonics and MPT, repeated t-test was utilised. The test shows that there was a significant difference pre- and post-intervention in HNR ($t = -7.57$, $p = .001$), harmonics ($t = -15.76$, $p = .001$), and MPT ($t = -7.48$, $p = .001$).

Discussion

This study is aimed to determine the results of speech and language therapy, using reinforced falsetto, for complete glottic closure in patients diagnosed with unilateral vocal fold paralysis, who were treated at the Laboratory of Voice at the 'Universidad del Desarrollo' in Chile, between 2015 and 2023. For this, an institutional database was used, where a total of 10 patients were included for analysis. The results of this study showed that all patients achieved a complete glottic closure after rehabilitation using the reinforced falsetto technique. In addition, all the acoustic parameters analysed improved after the therapy sessions.

Table 1. General information of the sample included for analysis.

Patient	1	2	3	4	5	6	7	8	9	10
General	Woman	Woman	Woman	Man	Man	Man	Woman	Man	Man	Man
Age	54	41	48	44	54	53	27	63	55	37
Aetiology	Idiopathic	Surgical	Surgical	latrogenic	latrogenic	latrogenic	latrogenic	Surgical	Surgical	Surgical
N° sessions	6.00	6.00	10.00	4.00	6.00	6.00	22.00	4.00	6.00	6.00
GRBAS	Severe	Moderate	Severe	Severe	Severe	Severe	Severe	Severe	Severe	Severe
MPT ¹	3.00	14.00	6.00	A ⁵	6.00	A ⁵	4.00	A ⁵	8.00	3.00
FO ²	305.00	24.01	251.00	A ⁵	208.00	A ⁵	272.00	A ⁵	464.00	184.00
Intensity	36.00	39.00	45.00	A ⁵	58.00	A ⁵	38.00	A ⁵	46.00	31.00
Jitter	3.27	2.37	>10.00	>10.00	9.10	>10.00	>10.00	>10.00	6.97	>10.00
Shimmer	0.81	0.46	>1.30	>1.30	0.90	>1.30	>1.30	>1.30	1.30	>1.30
HNR ³	1.23	2.42	<-1.00	<-1.00	1.76	<-1.00	<-1.00	<-1.00	-1.00	<-1.00
Harmonics	1100.00	1400.00	800.00	A ⁵	1200.00	A ⁵	1000.00	A ⁵	1500.00	1329.00
GC ⁴	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete
GRBAS	Mild	Normal	Mild	Normal	Mild	Mild	Mild	Mild	Normal	Normal
MPT ¹	15.00	19.00	14.00	21.00	17.00	17.00	14.00	13.00	18.00	20.00
FO ²	241.00	240.00	237.00	160.00	162.00	168.00	244.00	172.00	130.00	138.00
Intensity	54.00	61.00	51.00	56.00	65.00	53.00	52.00	51.00	53.00	42.00
Jitter	.93	.77	.96	.59	1.03	1.47	1.12	1.57	.67	.98
Shimmer	.32	.29	.31	.42	.36	.16	.46	.27	.23	.49
HNR ³	4.17	6.20	4.12	4.29	2.21	4.65	4.23	3.21	6.65	4.47
Harmonic	4600.00	5000.00	4700.00	5000.00	3800.00	5000.00	3500.00	4300.00	4400.00	4400.00
GC ⁴	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete

1. Maximum phonation time
2. Fundamental frequency
3. Harmonic-noise relation
4. Glottic closure
5. Aphonia

Table 2. Description of the categorical variables pre- and post-intervention using the reinforced falsetto strategy.

	Pre-intervention		Post-intervention	
	Frequency	%	Frequency	%
Severity of dysphonia (GRBAS)				
-Normal	0	0	4	40
-Mild	0	0	6	60
-Moderate	1	10	0	0
-Severe	9	90	0	0
Total	10	100	10	100
Glottic closure (VALI)				
-Complete	0	0	10	100
-Incomplete	10	100	0	0
Total	10	100	10	100

Table 3. Information of the descriptive statistic of numeric variables pre- and post-intervention using reinforced falsetto technique.

	Pre-intervention								Post-intervention							
	FO ¹	Int ²	Jitter	Shimmer	HNR ³	Harm ⁴	MPT ⁵	FO ¹	Int ²	Jitter	Shimmer	HNR ³	Harm ⁴	MPT ⁵		
Mean	291.50	43.67	8.23	1.13	-2.19	1189.86	6.29	189.20	53.80	1.00	0.33	4.42	4470.00	16.80		
Median	261.50	42.00	10.10	1.31	-1.10	1200.00	6.00	170.00	53.00	0.97	0.31	4.26	4500.00	17.00		
SD ⁶	90.26	8.06	3.02	.30	1.42	243.56	3.86	45.96	6.16	0.31	0.10	1.28	510.01	2.74		
P ⁷	25	238.75	6.05	.88	-1.10	1000.00	3.00	154.50	51.00	0.74	0.26	3.89	4175.00	14.00		
	50	261.50	10.10	1.31	-1.10	1200.00	6.00	170.00	53.00	0.97	0.31	4.26	4500.00	17.00		
	75	344.75	10.10	1.31	1.36	1400.00	8.00	240.25	57.25	1.20	0.43	5.03	5000.00	19.25		
ICR ⁸	106.00	11.50	4.05	.43	2.46	400.00	5.00	85.75	6.25	0.46	0.17	1.14	825.00	5.25		
Range	256.00	22.00	7.73	.85	3.52	700.00	11.00	114.00	23.00	0.98	0.33	4.44	1500.00	8.00		
Min	208.00	36.00	2.37	-.46	-1.10	800.00	3.00	130.00	42.00	0.59	0.16	2.21	3500.00	13.00		
Max	464.00	58.00	10.10	1.31	2.42	1500.00	14.00	244.00	65.00	1.57	0.49	6.65	5000.00	21.00		

- 1: Fundamental frequency.
- 2: Intensity in decibels.
- 3: Harmonic-noise relation.
- 4: Harmonics.
- 5: Maximum phonation time.
- 6: Standard deviation.
- 7: Percentile.
- 8: Interquartile range.

Glottic closure

The VALI protocol was used to register the change pre- and post-intervention of the UCVP. The complete glottic closure in all the patients included in the sample is related to the reinforced falsetto technique, which started with the falsetto register, moving progressively to the modal register. At this point, it is important to consider during the voice assessment the vocal functions that patients could perform and the compensations to achieve the glottic closure. This is because of the chance to access to specific vocal exercises which improve the subglottic pressure, and the function of the lateral cricoarytenoid and interarytenoid muscles, and consequently, the function of the thyroarytenoid muscle. Although the literature mentions that voice therapy lacks evidence in relation to the efficacy and a certain therapy program (Marqués et al., 2021), the use of the reinforced falsetto technique could be used as a strategy to improve the glottic closure in patients suffering from UVFP. Further, bearing in mind the current evidence (Herbst et al., 2011), which describes the physiology of the technique in singing voice and its relevance for the increasement of the cartilaginous and membranous adduction of the vocal folds, the use of the strategy could improve the glottic closure of the patients analysed.

Maximum phonation time

The significant improvement reported in the results section could be physiologically linked to the efficacy of the complete glottal closure, and then to the resistance of air flow by the vocal folds. The average increase of the MPT for 10 seconds post-therapy in the sample results in normative parameters is similar to the reported by Şen y Toğram (2021).

Voice intensity

Voice intensity could be regulated by three main factors: the subglottic pressure, which increases the fold vibration amplitude; the inter-glottic air flow and the laryngeal adjustment. They increase the harmonic excitation which is closed to the first formant of the vocal tract or adjust the vocal tract to coincide with one of the formants with one of the dominant harmonics in the spectrum (Zhang, 2016). The reinforced falsetto technique integrates the three main factors linked to voice intensity, then, the technique enhances this voice parameter in patients suffering from UVFP. That improvement is related to the reinforcement of the respiratory support, which raises the subglottic pressure. Consequently, this creates an audible falsetto using the vowel /u/ due to the action of the lateral cricoarytenoid, cricoarytenoid and thyroarytenoid muscles. This configuration allows the fit of both the first formant and the first harmonic. As a result, the patients of the sample achieved a significant voice intensity after the therapy sessions.

Fundamental frequency

At the voice assessment point, 4 out of the 10 patients had aphonia. Due to this, it was not possible to register their F0 pre-intervention. After the rehabilitation process, and, considering all the cases again the clinical information available, there was a significant change in the vocal parameter, dropping from higher frequencies. This is because of the reinforced falsetto technique and the falsetto register, to gradually pass to a modal register due to the activation of the thyroarytenoid muscle, the paralysed muscle or the correct compensation of the vocal fold to the medium line. The analysis performed by sex pre- and post-intervention showed there was no significant difference in the F0. In the case of men, there was information of the F0 pre- and post-intervention in two cases. Qualitatively, the mean of the F0 pre-intervention was 336 Hz changing to 155 Hz post-therapy, which is close to the normative parameters given by Jackson-Menaldi (2019). In the case of women, there was a similar result in which the F0 changed from 269.5 Hz to 240.5 Hz pre- and post-intervention, reaching the normative parameters described by the literature.

Harmonics

According to Cecconello (2012), the vocal harmonic component allows to determine the severity of the dysphonia. Using the reinforced falsetto technique, the mean of the parameter increased significantly. The new parameter values were close to the normative reported by the evidence, coinciding with normal voices or minimum altered voices. Physiologically, it could be related to an increase of vocal fold contact, improving the harmonic component and reducing the noise generated by the air flow due to the lack of complete glottic closure.

Severity of the dysphonia

Using the GRBAS scale, it was possible to notice a significant change in the sample pre- and post-intervention using the reinforced falsetto technique. This result is in line with the literature that mentions the speech therapy for voice disorders produces significant improvements, linked to the severity of auditory-perceptual parameters produced by the UVFP (Busto et al., 2015).

Therapeutic potential of the reinforced falsetto technique in UVFP: physiological benefits and clinical considerations

Although traditional strategies have been extensively mentioned by the literature and studied for the rehabilitation of UVFP, the reinforced falsetto has not been discussed nor used in depth, despite the improvement of the glottal closure (Bekerman et al., 2015). Reinforced falsetto represents a promising therapeutic technique

in the treatment of UVFP due to its distinctive physiological features. During its performance, the ability to control laryngeal height and raise the soft palate provides greater supralaryngeal resonance area (Aguilar, 2022). This greater area allows sounds to be amplified and modified before leaving the vocal tract, promoting more versatile and higher quality voice emissions. In patients suffering from UVFP, this benefit may be especially relevant as the strategy allows patients to compensate their phonation limitations caused by their medical condition. Furthermore, the reinforced falsetto offers the possibility of making substantial dynamic phonation gradations (Aguilar, 2022), allowing the precise adjustment of the voice intensity. This dynamic control capability is valuable for patients suffering from UVFP as it allows them effectively to adapt their voice. Research performed on men and women highlights the fact that the transition from lower abduction to higher adduction in falsetto register produces an increase in both cartilaginous and membranous adduction of the vocal folds (Herbst et al., 2011). This increase of the vocal fold adduction may improve both the coordination and the vocal quality in patients suffering from UVFP, producing a more efficient voice, reducing the fatigue during phonation and the need for muscular compensation. A correct adduction of the vocal folds can optimise the respiratory function during vocal production, which contributes to better vocal resistance. In the field of vocal therapy, falsetto is distinguished as a technique that facilitates sounds by relaxing the thyroarytenoid muscle, increasing subglottic pressure and contracting the cricothyroid muscle during the emission of hyper-acute sounds (Cobeta et al., 2013). The UVCP could generate inappropriate muscular compensations, such as excessive tension of the thyroarytenoid muscle which results in strained vocal emission and excessive effort. Relaxation of this muscle reduces muscle tension and promotes natural vocal production. Subglottic pressure is essential for sustained vocal production. In UVFP an increase of subglottic pressure can compensate the function of the vocal fold paralysed, facilitating airflow through the glottis, improving vocal vibration and sound quality. Finally, UVFP can decrease the tension and function of the laryngeal muscles which negatively affects the patient's ability to generate pressure and vocal control. The cricothyroid muscle contraction can counteract this weakness by increasing tension on the contralateral vocal fold, improving adduction and overall vocal quality.

In this study, using the reinforced falsetto technique, changes in voice patterns were noticeable in therapy sessions of 50 minutes, taking in total between four and 22 rehabilitation meetings. There was an improvement in all the auditory-perceptual parameters of the voice after the rehabilitation process. This initial research supports the use of the reinforced falsetto technique, as the results in the sample show significant enhancements in the glottal closure and the auditory-perceptual parameters of the voice.

Bias

The sample studied did not have a period of observation pre-intervention, as patients immediately started the voice rehabilitation process to attend their communications needs. Further, there was no information available on the aetiology of UVFP. There was no possible way of knowing if a patient could have experienced a spontaneous recovery. However, the literature mentions that a spontaneous recovery does not guarantee a proper movement of the vocal fold, due to a variable and non-selective synkinesis process (Bothe et al., 2014, Busto et al., 2016). Even without knowing if there were cases of spontaneous recovery, the reinforced falsetto technique could offer some benefits to the vocal function recovery.

Limitations

Despite the benefits previously reported of the reinforced falsetto as a technique for the rehabilitation of UVFP in this sample, it was not possible to generalise the results of this study due to its design and the sample size. However, this study is a first approach to perform extra research. During the review of the database for selecting the participants, many patients were excluded as some information was not available. Also, in the sample studied, it was not possible to analyse all variables pre- and post-intervention, as some of them were impossible to register due to the aphonia, namely by harmonics, FO and intensity. Further, the database had not information about the grade of injury of the recurrent laryngeal nerve nor data of the electromyography pre and post rehabilitation. For this reason, a neurolaryngologic analysis was not able to carry out in order to know in each patient if they presented spontaneous reinnervation of the vocal fold paralysed or if they compensate the glottic closure. Moreover, information of the laryngeal images contained in the database exclusively reported data of the glottic closure, excluding other value information such as the supraglottic activity which could be linked to the compensation of the healthy vocal fold, the impact of the technique on the mucosal wave, the vertical level of the vocal folds, among others. Finally, an additional limitation was the analysis of the FO by sex, which could not be performed as a consequence of the sample size.

Projection

Extra research of UVFP and the use of reinforced falsetto as strategy of rehabilitation is mandatory in order to obtain neurolaryngologic, acoustic and instrumental data which could be generalisable to the population, and, possibly, to support the use of this technique with strong evidence.

Conclusions

In the sample studied, the reinforced falsetto technique was significantly effective for increasing glottic closure. Before therapy, all the patients had incomplete glottic closure, and all achieved a complete glottic closure after the rehabilitation sessions. Furthermore, there was a statistically significant improvement in all the

analysed vocal variables. Due to this, the reinforced falsetto technique could be useful for the rehabilitation of unilateral vocal fold paralysis. Further research is suggested in this line by considering an experimental design in order to generalise the findings to the wider population.

Authorship declaration

Patricio Orellana: Conceptualization; Data collection; Data curation; First draft writing; Writing revised version.
 Felipe Rosales: Conceptualization; Methodology; Statistics; First draft writing; Writing revised version.
 Giovanna Monichi: First draft writing; Writing revised version.

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