Voice outcome of glottoplasty in trans women

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Abstract

Purpose: This study investigates the short- and longer-term effects of glottoplasty up to 6 months after surgery on acoustic voice parameters, listener perceptions, and client's satisfaction in trans women. Secondly, the impact of chondrolaryngoplasty and voice therapy on the glottopasty outcomes was investigated.

Method: A prospective longitudinal non-controlled trial was used. Thirty-five trans women undergoing glottoplasty or a combination of glottopasty and chondrolaryngoplasty were included in this study. A voice assessment was conducted before surgery and 1 week, 1 month and 6 months after surgery. The following outcome parameters were measured: fundamental frequency (f_o), intensity, frequency and intensity range, Dysphonia Severity Index (DSI), Acoustic Voice Quality Index (AVQI), Voice Handicap Index (VHI), Trans Woman Voice Questionnaire (TWVQ), and visual analogue scales (VAS) measuring client's satisfaction. Listener perceptions of masculinity-femininity were collected using a listening experiment.

Results: Significant differences over time were found for all f_o and intensity parameters, DSI, AVQI, VHI and TWVQ scores. Listener perception and self-perception of femininity was higher after surgery. Significant differences in evolution of listener perceptions were found between the groups with and without voice therapy.

Conclusion: Glottoplasty improves voice related quality of life and is an effective method to increase the f_o and associated perceptual femininity. After glottoplasty an immediate and short-term decrease in voice quality, vocal capacity and frequency range was measured with a progressive recovery on the longer term. Long term side effects of glottoplasty are a reduction in speaking intensity and intensity range. Voice therapy seems to improve the outcomes of glottoplasty, but should be further investigated in future studies.

Introduction

Vocal difficulties related to gender incongruence can have a major impact on psychosocial functioning [1]. For transgender men (trans men), a more masculine voice is typically achieved through gender affirming hormonal treatment [2]. For transgender women (trans women), hormonal treatment does not have a perceivable impact on the voice [3]. In this group, feminization of the voice can be obtained through voice therapy or voice surgery.

The goal of voice interventions is to help transgender clients developing a gender congruent communication by addressing these aspects of communication that play a role in listener gender perceptions. The systematic review of Leung et al. [4] showed that fundamental frequency (f_o) is an important voice parameter explaining 42% of variance in listener gender perceptions. Maintaining a mean speaking f_o higher than 180Hz with a lower limit of 140Hz and an upper limit of 300Hz contributes to a female gender perception. Recent literature and meta-analysis showed that voice therapy results in a mean f_o increase of 30Hz during reading (range: 14-71 Hz) [5, 6]. However, in 20% of the trans women seeking voice feminization, voice therapy is not satisfactory or not preferred by the client, and voice surgery is considered to increase f_o [7].

The aim of voice feminization surgery is to increase the pitch without altering the voice quality and phonatory function of the vocal folds, which is difficult and challenging [7, 8]. Voice feminization surgery was introduced in the eighties by Isshiki in the form of cricothyroid approximation, also called type IV thyroplasty (Isshiki 1979). Over the years, three main surgical voice feminization techniques were described in the literature to achieve pitch elevation: techniques increasing the tension of the vocal folds, such as cricothyroid approximation; techniques decreasing the vocal fold mass, such as laser reduction; and techniques decreasing the vibratory length of the vocal folds, such as glottoplasty [7]. In recent reviews, outcomes of the surgical techniques were compared and results showed that all techniques were satisfactory and led to an increase in f_o, but procedures that shorten the vibratory length of the vocal folds resulted in the largest increase in f_o [6, 9].

Glottoplasty is the most frequently used and studied technique in the last decade [6, 7, 9]. It is most commonly performed endoscopically; here, the mucosa of the anterior part of the vocal folds is resected and both vocal folds are sutured together, which creates a glottal webbing, reducing the effective vibratory length of the vocal folds. After glottoplasty a mean increase in f_o of 79Hz can be expected [9]. However, large variability in outcomes has been reported. A meta-analysis of voice feminization surgery revealed a heterogeneity regarding the f_o increase of I^2= 90% for glottoplasty, compared to only 29% for cricothyroid approximation [9]. The increase after glottoplasty ranges from 20Hz [10] to 112Hz [11]. While having a desired effect on pitch, negative side effects of glottoplasty

on voice quality are common, including decreased loudness and frequency range, and increased roughness and vocal effort [7, 9, 12]. Many of the studies are limited by a retrospective study design, low power, and short follow-up, which emphasizes the need for prospective studies with larger sample sizes including longer follow-up, and multidimensional voice assessments pre- and postoperative [9].

Although considerable research regarding glottoplasty outcomes has been carried out, largely insufficient data exist, and prospective studies are lacking. The primary purpose of this study is to determine the short- and longer-term effect of glottoplasty on f_o and intensity (a), voice range (b), voice quality (c), listener perceptions of femininity and masculinity (d), psychosocial functioning and client's satisfaction with voice (e). The secondary purpose of this study was to investigate whether a combined chondrolaryngoplasty and voice therapy influences the f_o outcomes of glottoplasty.

Methodology

A prospective longitudinal non-controlled trial was used and approved by the Ethics Committee of xx University Hospital (registration number: B670201942337). A written informed consent was signed by each participant.

Participants

Trans women undergoing a glottoplasty at xx University Hospital were invited to participate in the study between January 2020 and December 2021. Inclusion criteria were an established diagnosis of gender dysphoria and a female gender identity confirmed by the interdisciplinary Gender team at the xx University Hospital (xx) and according to the criteria of the WPATH [13], minimum age of 18 years, Dutch speaker, and seeking voice feminization care by means of voice surgery. Exclusion criteria were prior pitch elevation surgery, presence of organic voice pathology (observed by videolaryngostroboscopic examination of the vocal folds), or history of neurological disorders.

Surgical procedure

All participants underwent a Wendler glottoplasty under general anesthesia with orotracheal intubation by the same otolaryngologist (XX). Surgery proceeded as follows: mucosal resection using cold instruments, and creating a glottal web using 2 sutures PDS 5/0, including the medial portion of the thyro-arytenoideus muscle, according to current standard of care. In the postoperative phase,

patients received complete voice rest during the first week. Ten trans women (10/35, 29%) underwent a combination of a glottoplasty and chondrolaryngoplasty.

Pre- and postoperative voice assessment

A standardized multidimensional voice assessment consisting of acoustic and perceptual measurements and patient reported outcome measures (PROMS) was used to evaluate the participants' voices. Identical procedures were used before glottoplasty (pre) and one week (post 1), 4 weeks (post 2) and 6 months (post 3) postoperative. Assessments were performed by 4 speech language pathologists (SLPs) (XX, XX, XX, XX) of the gender voice clinic.

Voice Recordings

Voice recordings were performed in a sound-treated room at xx University Hospital using a Samson C01U Pro USB Studio Condenser Microphone, digitized at a sampling rate of 44.1 kHz and a mouth-to-microphone distance of 15 cm. The calibration procedure of Maryn and Zarowski [14] was used to calibrate the microphone for intensity. The samples contained a sustained vowel /a:/, continuous speech during reading and spontaneous speech. For the reading task, the phonetically balanced text "Papa en Marloes" [15] was used. To collect the spontaneous speech sample, participants were instructed to talk about their leisure activities. The mean signal to noise ratio (SNR) of the recordings was 28 (SD: 4.9, range: 20-40).

Outcome parameters

(a) Intensity and f_o

Speech samples were analysed with the Praat software program for acoustic analysis [16]. For each speech sample, the median intensity (decibels, dB), the median f_o (Hertz, Hz), and percentiles 25 and 75 of f_o were calculated.

(b) Voice Range Profile (VRP)

The VRP was determined by the Computerized Speech Lab (CSL, model 4500, KayPENTAX, Montvale, NY), using a Shure SM-48 microphone located at a distance of 15 cm from the mouth and angled at 90°. This assessment included determination of the highest and the lowest f_o (F-high, F-low in Hz) and intensity (I-high, I-low in dB) [17].

(c) Vocal quality

The Dysphonia Severity Index (DSI) is a multiparametric approach designed to establish an objective and quantitative correlate of the perceived voice quality [18]. It is based on a weighted combination

of 4 voice parameters: maximum phonation time (MPT, s), F-high, I-low, and jitter (%). The DSI is constructed as 0.13 MPT + 0.0053 F-high – 0.26 I-low – 1.18 jitter +12.4. The index ranges from -5 to +5 for severely dysphonic to normal voices and has a cut-off score of 1.6 [19]. The MPT was determined by asking the subjects to sustain the vowel /a:/ at habitual pitch and loudness after a maximal inspiration (3 attempts). For the determination of the jitter, a recording of the vowel /a:/ (midvowel segment) at habitual pitch and loudness was performed using the Multidimensional Voice Program (MDVP) of the CSL.

The Acoustic Voice Quality Index (AVQI) is a robust and valid method to quantify the severity of overall dysphonia based on both continuous speech and sustained vowel recordings [20]. This multiparameter index consists of a weighted combination of 6 voice parameters: smoothed cepstral peak prominence (CPPS), harmonics-to-noise ratio (HNR), shimmer local (SL), shimmer local dB (SLdB), general slope of the spectrum (slope) and tilt of the regression line through the spectrum (tilt). The formula is constructed as 9.072 − 0.245 × CPPs − 0.161 × HNR − 0.470 × SL + 6.158 × SLdB − 0.071 × Slope − 0.170 × Tilt and ranges from 0 to 10. The higher the score of the AVQI, the worse is the overall voice quality. The cut-off score between normal and dysphonic voices is 2.95 [20].

(d) Listener perceptions of femininity and masculinity

A listening experiment to rate masculinity-femininity of the speech samples (n=115) of the pre and post 2 and 3 conditions was conducted using the online REDCap [21] tool. Cisgender (cis) and gender diverse listeners were recruited as naïve listeners via convenience sampling. They were blinded to the purpose of the study and the gender(identity) of the speakers.

To avoid listening fatigue and loss of concentration, listeners were randomly assigned to 2 groups with each group rating half of the samples. They were instructed to score the speech samples for masculinity-femininity on a visual analogue scale (VAS) in a quiet room, using headphones. The anchors of the VAS corresponded with ‘very masculine’ (left side; score 0) and ‘very feminine’ (right side; score 100). The listeners were instructed to treat the middle of the scale as ambiguous or neither feminine nor masculine. Two extra questions (rating voice quality and age on a VAS) were included to reduce the likelihood that listeners would identify the objectives of the study. A test sample was included to adjust the volume of the headphones to a comfortable intensity level. The speech samples consisted of the first and last 2 sentences of the reading task. Ten speech samples of cis men and cis women were incorporated to distract the listeners from the objective of the study in order to avoid biased answers as much as possible. Ten double samples of the transgender women were added to calculate the intra-rater reliability.

(e) Client's satisfaction and psychosocial functioning

The Dutch version [22] of the Trans Woman Voice Questionnaire (TWVQ) [23] was used to investigate the transgender women's experiences with their voices. The self-perception of vocal symptoms of the speaking voice was investigated using the Dutch version of the Voice Handicap Index (VHI) [24, 25]. Both TWVQ and VHI are self-administered questionnaires consisting of 30 statements evaluated on a Likert scale. The higher the scores, the more perceived disability due to voice difficulties. For the VHI a cut-off scores of 20 was determined to identify voice symptom related disability [24].

The participants were also asked to rate several VAS (Appendix A). The first 2 VAS consisted of rating the current masculinity/femininity and the pitch of their voice. After glottoplasty (i.e. all speech assessments except for the pre measurement), they were asked four more questions with a VAS, i.e. whether their voice sounded more feminine, higher and rough compared to their voice before glottoplasty, and whether they needed voice therapy.

Statistical analysis

SPSS 27.0 (SPSS Corp., Chicago, IL, USA) was used for the statistical analysis of the data. Analyses were conducted at $\alpha = 0.05$. Linear mixed models (LMM) were used to compare the data over time on each continuous outcome measure, using the restricted maximum likelihood estimation and scaled identity covariance structure. Time was specified as a fixed factor. To measure the impact of chondrolaryngoplasty and voice therapy, LMM were used with time, Group and Time × Group interactions as fixed factors. A random intercept for participants was included. Model assumptions were checked by inspecting whether residuals were normally distributed. Inter-rater reliability was calculated for the listener experiment by means of two-way mixed intraclass correlation coeffients (ICCs), type consistency (single measures). ICCs were interpreted following the classification of Altman (ICC < 0.20: poor, 0.21–0.40: fair, 0.41–0.60: moderate, 0.61–0.80: good, 0.81–33 1.00: very good) [26].

Results

Participants characteristics

The subject group consisted of 35 trans women with a mean age of 32.2 years (SD: 11.8, range: 19-64 years). In this group, 81% (n=27) followed pre-operative speech therapy, 49% (n=17) followed post-operative speech therapy and 74% (n=26) of the trans women were non-smokers.

Listeners characteristics

Forty-seven listeners with a mean age of 36.8 (SD: 14.58, range: 20-68) were included in the listening experiment. All participants were native Dutch speakers and had a self-reported normal hearing. Listeners' characteristics are presented in Table 1.

Primary outcomes

(a-c) Acoustic outcome parameters

The results of the acoustic outcome parameters before and after surgery are presented in Table 2. Significant changes over time were found for all acoustic parameters, except for I-low and DSI. Pairwise comparisons between the pre an postoperative conditions are displayed in Table 3.

(d) Listener perceptions of femininity and masculinity

Listeners rated the speech of the trans women significantly different at the three time points ($p<0.001$; $t=17.47$, df: 26.08). Mean femininity scores changed from 37.6 (SD: 19.2, range: 8.7-77.8) before glottoplasty to 55.4 (SD: 17.4, range: 16.9-82.6) and 61.1 (SD: 15.8, range: 32.1-85.8), respectively 1 month and 6 months after surgery (Figure 1). The voices of all participants, except 2, were rated more feminine after surgery. Intra-rater reliability of the 10 double samples showed an ICC of 0.873 (SD: 0.1261, range: 0.456 – 0.994). The ICC for inter-rater reliability was 0.592 (95% CI: 0.411 – 0.770)

(e) Client's satisfaction and psychosocial functioning

Changes in VHI ($p<0.001$) and TWVQ ($p<0.001$) are presented in Figure 2 and 3, respectively. The first week after glottoplasty vocal impairment measured by the VHI temporarily worsened (pre mean: 56, SD:22, range: 15-105; post 1 mean: 68, SD 22, range: 30-113; $p=0.008$). After 1 month (post 2 mean: 44, SD: 23, range: 2-108) and 6 months (post 3 mean: 36, SD: 22, range 0-87), psychosocial impairment related to voice symptoms significantly decreased compared to the pre-operative condition (resp. $p=0.018$ and $p<0.001$). The TWVQ scores were significantly lower 1 month (mean: 59, SD: 18, range: 30-102; $p<0.001$) and 6 months after surgery (post 3 mean: 51, SD: 17, range: 30-93; $p<0.001$) compared to the pre-operative condition (pre mean: 84, SD 17, range 53-116). No significant differences were found between the pre and post 1 condition (post 1 mean: 68, SD: 22, range: 30-113). Self-perception VAS scores are presented in Table 4.

Impact of a combined chondrolaryngoplasty

No significant differences were found for the outcome parameters: median f_o during reading (LMM, p=0.742), TWVQ (LMM, p=0.381) and listener perceptions of speaker gender (LMM VAS, p= 0.880) between participants undergoing a glottoplasty with and without chondrolaryngoplasty.

Impact of combined voice therapy

Figure 4 shows the results of the f_o changes over time in the groups with and without voice therapy (LMM, p= 0.076). Changes in listener perceptions of speaker gender (VAS) were significantly different in both groups (LMM, p= 0.047, figure 5). No differences in evolution of TWVQ scores were found between both groups (p=0.284).

Discussion

In this study, the short- and longer term outcomes of glottoplasty in trans women were investigated using a prospective study and a multidimensional voice assessment measuring f_o and intensity, voice range, voice quality, listener perceptions of femininity and masculinity, psychosocial functioning and client's satisfaction with voice.

The results of the acoustic analysis showed a mean f_o increase of 53.21 Hz during reading and 42.01 Hz during spontaneous speech one month post-operative. The f_o increase in this study is smaller compared to the mean f_o increase of 72.21Hz and 78.98Hz reported in previous meta-analyses [6, 9] and in line with the f_o increases reported in the recent studies of Meister et al. and Kim et al. [8, 27]. During the post-operative follow-up period of 6 months, the f_o increase remained stable. However, the first week after surgery there was a large degree of uncertainty in f_o data as shown by the large confidence interval. SD of f_o was smaller 1 month and 6 months after surgery compared to 1 week postoperative.

Lower and upper limits of f_o significantly increased after glottoplasty in all speech tasks. Measurements of f_o differed between the speech tasks and were generally the lowest in spontaneous speech and the highest in a sustained vowel. Maintaining a mean f_o greater than 180Hz in spontaneous speech with a lower limit of 140Hz and an upper limit of 300Hz contributes to a female gender perception [4]. However, most trans women in this study did not reach a median f_o of

more than 180Hz during spontaneous speech after glottoplasty. The mean post-operative lower limits, measured as the 25th percentile of the f_o, were above 140Hz for every speech task. The acoustic results are in line with the results of the listening experiment showing a significant increase in femininity. The speech samples were rated 18% and 24% more feminine after 1 and 6 months, respectively. In 94% of the speech samples, the voices were rated more feminine after surgery. However, most postoperative speech samples were rated in the middle of masculinity-femininity VAS, reflecting a more gender ambiguous voice. These results are in accordance with recent literature showing that altering pitch alone is not sufficient to change listener perceptions of speaker gender from male to female [4]. In the 2 patients showing no increase in femininity perception by listeners, no increase in f_o was obtained after surgery. Analysis of the individual data revealed that one of them already had a femininity score of 77.8% pre-operative and underwent a combination of a glottoplasty and chondrolaryngoplasty. The other participant was referred for a revision of the glottoplasty. To what extend voice quality changes had an impact on listener perceptions of femininity-masculinity is subject for further research. The meta-analysis of Leung et al. [4] revealed mixed results as to the contribution of a breathy voice quality to gender perception. Attributions of listeners regarding post-operative roughness can vary across cultures. Gender perception is a complex phenomenon that is influenced by socio-cultural forces [28].

In a computational simulation study, Titze et al. [12] investigated the trade-offs of glottoplasty and found that f_o increases were associated with decreases in intensity. These theoretical findings are confirmed in this clinical study showing an immediate post-op mean intensity decrease of 4.3 dB in spontaneous speech. Six months after surgery the intensity remained significantly lower compared to the pre-operative condition (-5.5dB). In glottoplasty, a compromise should be made between pitch elevation and reduction in acoustic power. In this study, the relatively small reduction in acoustic power can be related to the limited increase in f_o. Some clinical studies reported a decrease in loudness as well [8]. However, comparison with other studies is difficult, as intensity is often not measured and therefore not included as an outcome parameter in the recent meta-analyses [6, 7]. Another common trade-off of glottoplasty reported in the literature was a decrease of voice quality and capacity including a decrease in vocal range and phonation time and increased roughness, vocal effort, and instability [6, 29]. However, the degree of post-operative dysphonia was variable and studies reported contradictory findings [8, 10, 27, 29-32]. Most studies used a retrospective study design with variable postoperative time points [8, 27, 30-33] making it difficult to study evolution and recovery of side-effects. The results of this study revealed an immediate and short-term negative impact on the voice quality and vocal capacity with a progressive recovery. Six months after surgery, no significant differences in DSI and AVQI were measured compared to the preoperative condition. In

the frequency range, the same evolution was measured with a significant decrease 1 week and 1 month after surgery and a progressive recovery 6 months after surgery. These longer term results are in accordance with the prospective study of Aires et al. [29] showing no significant differences in voice quality and frequency range 6 months postoperative. Yilmaz et al. [34] investigated single acoustic perturbation measures (jitter, shimmer, NHR) 1 year postoperative using a prospective cohort study and did not found significant changes with the preoperative condition. The intensity range in this study, did not show a full recovery after 6 months and can be regarded as a long-term side-effect together with the decrease of the speaking intensity. This is the first study, that prospectively investigated the evolution of acoustic trade-offs at different time points. Trans women undergoing glottoplasty should be aware of a temporary decrease in voice quality (AVQI), vocal capacity (DSI) and frequency range and a longer-term decrease in speaking intensity and intensity range.

The ultimate goal of voice interventions in trans women is to reduce the voice gender incongruence experienced by the individual client. Therefore, PROMS are indispensable and clinically more decisive than objective acoustic outcome parameters. In this study a combination of standardized (TWVQ and VHI) and unstandardized (VAS) PROMS were used. The results show a temporary increase in impact of vocal symptoms, measured by the VHI, immediately after surgery. However, 1 month and 6 months after surgery the VHI scores were significantly lower compared to the pre-operative scores, reflecting a better voice related quality of life. The TWVQ was specifically designed to measure trans women's experiences with their voices. Immediately after surgery, the TWVQ scores remained the same, probably because communication experiences using the post-operative voice were limited due to the prescribed voice rest. One month and 6 months after surgery, TWVQ scores were significantly lower showing a positive impact of the surgery on the quality of life of the trans women. In line with the perceptions of listeners, participants rated their voice more feminine after surgery on a VAS. Their scores increased progressively and were slightly lower compared to the mean scores of the listening panel. In the study of Paltura et al. [35], individuals reported that their voice did not sufficiently project femininity after glottoplasty. The authors recommended voice therapy as a possible approach to achieve a satisfactory feminine voice. The VAS scores in this study also confirmed a high need for post-operative voice therapy. Nolan et al. [6] concluded that postoperative voice therapy further increases f_0 and the feminine resonance, and also stabilizes the voice.

The results of this study showed that outcomes of glottoplasty were different in trans women following voice therapy. Femininity scores were higher at baseline and 1 month after surgery in trans women following voice therapy. Trans women undergoing glottoplasty without voice therapy showed a higher increase in perceptual femininity scores after surgery, although the mean femininity

scores remained lower 1 month after surgery compared to trans women who followed voice therapy. Moreover, a trend of higher f_o scores and a faster increase in f_o was observed in the group following voice therapy. However, no differences were found in evolution of TWVQ-scores. The trans women in this study seemed equally satisfied after glottoplasty with or without voice therapy. However, the absence of a standardized pre- and postoperative voice therapy protocol and the non-randomized design of this study are important limitations that should be addressed in future research.

Some trans women chose to combine glottoplasty with a chondrolaryngoplasty. However, effects of chondrolaryngoplasty on voice characteristics are not well investigated yet. Although Aires et al. [36] reported no impact of chondrolaryngoplasty on f_o and perceptual outcomes, self-reported hoarseness was a complication in 36.2% of the patients [37]. Whether or not glottoplasty was combined with a chondrolaryngoplasty did not influence the primary outcome parameters in this study. However, in future studies the impact of chondrolaryngoplasty on the different aspects of the voice should be further investigated.

Conclusion:

This is the first prospective 6 months follow-up study investigating the immediate, short-term and longer-term outcome of glottoplasty using a multidimensional voice assessment in a cohort of 35 trans women. Results showed that glottoplasty improved voice related quality of life and was an effective method to increase the f_o and associated perceptual femininity. However, temporary side-effects like decrease in voice quality (AVQI), vocal capacity (DSI) and frequency range as well as a longer-term decrease in speaking intensity and intensity range should be taken into account. Better acoustic and perceptual outcomes were found in trans women following pre- or postoperative voice therapy, whereas chondrolaryngoplasty combined with glottoplasty did not seem to influence the outcomes.

Tables

Table 1: Listeners' characteristics

	cis women	cis men	trans women	trans men	gender non-binary persons
n	21	20	2	1	3
Age					
mean	33.1	41.4	43.0	26	31.7
SD	14.77	14.73	9.90		10.50
Range	21-68	20-60	36-50		21-42

Abbreviations: SD: standard deviation

Table 2: Results of the acoustic outcome parameters before and after glottoplasty

	pre				post 1 week				post 1 month				post 6 months				p-value
Acoustic parameters	**mean**	SD	min	max	**mean**	SD	min	max	**mean**	SD	min	max	**mean**	SD	min	max	
Intensity																	
vowel a	**71.88**	4.71	63.19	82.38	**69.28**	7.5	55.28	84.15	**70.35**	6.03	54.03	86.61	**70.98**	7.33	59.71	85.18	< 0.001*
reading	**69.68**	5.49	60.65	85.38	**65.37**	7.47	45.06	74.89	**68.5**	4.95	56.87	82.57	**65.77**	6.63	52.26	77.92	< 0.001*
sp. speech	**67.55**	6.23	55.13	84.08	**63.27**	5.94	49.08	73.12	**65.49**	6.03	45.89	75.73	**62.1**	7.6	44.81	73.73	< 0.001*
f_0																	
vowel a																	
median fo	**140.49**	30.86	86.92	206.5	**171.21**	48.88	94.5	297.55	**193.7**	36.54	138.5	275.57	**181.34**	33.16	107.47	227.22	< 0.001*
pc 25	**137.32**	32.72	74.08	205.43	**160.72**	54.22	76.62	293.48	**179.07**	46.55	61.57	267.25	**179.79**	33.14	105.65	226.62	< 0.001*
pc 75	**141.58**	30.87	87.55	207.48	**173.98**	49.18	96.35	299.38	**195.6**	36.84	140.39	280.68	**188.44**	27.98	139.79	227.84	< 0.001*
reading																	
median	**135.67**	22.89	87.64	185.05	**177.84**	73.75	107.29	495.13	**179.62**	25.78	126.35	229.02	**171.9**	25.68	139.59	227.09	< 0.001*
pc 25	**121.49**	18.27	83.09	158.3	**160.6**	63.66	101.3	437	**165.7**	24.75	118.44	209.97	**157.53**	23.71	130.11	209.01	< 0.001*
pc 75	**152.24**	27.68	93.21	218.9	**204.22**	81.96	113.79	540.42	**196.72**	27.15	138.99	244.91	**191.16**	27.69	152.7	248.15	< 0.001*
sp. speech																	
median	**128.02**	17.43	90.14	164.84	**168.36**	54.87	109.63	298.26	**170.03**	27.39	119.67	227.41	**167.21**	31.05	134.31	232.51	< 0.001*
pc 25	**117.69**	15.35	84.99	147.51	**152.79**	50.26	97.13	276.8	**159.83**	26.15	115.13	214.91	**155.08**	26.21	126.73	212.35	< 0.001*
pc 75	**139.8**	19	95.65	181.34	**183.48**	59.48	118.13	324.97	**183.58**	29.3	129.6	242.65	**179.13**	33.76	140.36	254.13	< 0.001*
VRP																	
I-low	**60.09**	3.22	53	66	**58.42**	3.42	51	63	**61.52**	4.22	54	75	**60.67**	4.49	53	69	0.111
I-high	**97.29**	9.43	69	120	**81.73**	6.72	74	92	**88.15**	7.57	72	104	**90.28**	6.94	76	100	<0.001*
I-range	**37.20**	9.94	10	67	**23.09**	6.28	13	34	**26.64**	8.14	10	41	**29.61**	7.29	16	44	<0.001*
F-low	**93.69**	16.33	67	130.8	**126.82**	25.44	87.31	174	**139.31**	25.09	103	185	**131.56**	28.04	88	174.61	<0.001*
F-high	**591.91**	164.57	261	987.77	**399.98**	121.01	261.63	659.26	**513.62**	167.28	277	880	**523.14**	200.11	261	880	<0.001*
F-range	**498.39**	165.71	169	905.36	**273.96**	124.23	103	528.45	**374.31**	171.47	119	733.14	**391.57**	201.65	151	741.41	<0.001*
Indices																	
DSI	**0.8**	2.1	-3.7	6.4	**-2.1**	3	-6.5	1.9	**-2.2**	4.2	-10	9.4	**-0.2**	3.2	-6.1	7.4	0.852
AVQI	**3.27**	1.16	1.2	6.36	**5.57**	1.78	2.89	8.6	**4.62**	1.37	1.7	8.02	**3.91**	1.09	1.66	5.65	< 0.001*

*Abbreviations: sp.: spontaneous; SD: Standard Deviation; min: minimum; max: maximum; pc: percentile; VRP: Voice Range Profile; I-low: lowest intensity; I-high: highest intensity, F-low: lowest frequency; F-high: highest frequency; DSI: Dysphonia Severity Index; AVQI: Acoustic Voice Quality Index; *: p<0.05*

Table 3: Pairwise comparisons of the outcome parameters before and after glottoplasty

	Pre – post 1 week					Pre – post 1 month					Pre- post 6 months				
Acoustic parameters	p-value	EMD	95% CI		df	p-value	EMD	95% CI		df	p-value	EMD	95% CI		df
			Lower bound	Upper bound				Lower bound	Upper bound				Lower bound	Upper bound	
Intensity															
a	0.089	2.993	-0.476	6.461	36.967	0.239	1.742	-1.197	4.68	45.602	.585	0.870	-2.31	4.05	52.91
reading	0.017*	5.014	0.995	9.033	22.672	0.433	1.181	-1.832	4.193	39.213	.020*	3.572	0.575	6.569	59.883
sp. speech	0.021*	4.427	0.758	8.097	17.006	0.174	2.145	-1.007	5.297	25.922	.011*	5.625	1.471	9.779	14.63
f_0															
a															
median fo	0.006*	-27.209	-45.95	-8.468	38.11	<.001*	-51.824	-66.896	-36.753	51.726	<.001*	-39.624	-56.04	-23.209	76.28
pc 25	0.047	-22.208	-44.124	-0.292	42.176	<.001*	-40.857	-59.002	-22.713	72.352	<.001*	-41.739	-63.256	-20.222	77.931
pc 75	0.003*	-28.284	-46.229	-10.338	36.497	<.001*	-52.56	-66.714	-38.405	48.096	<.001*	-44.31	-59.606	-29.014	70.303
reading															
median	0.025*	-41.589	-77.62	-5.558	24.887	<.001*	-43.512	-63.728	-23.296	283.393	.003*	-35.792	-59.456	-12.128	413.546
pc 25	0.014*	-38.676	-68.721	-8.63	27.773	<.001*	-43.874	-61.547	-26.202	385.098	<.001*	-35.832	-56.572	-15.093	567.128
pc 75	0.003*	-49.471	-80.825	-18.118	28.631	<.001*	-44.152	-57.084	-31.221	56.998	<.001*	-37.323	-51.893	-22.752	67.497
sp. speech															
median	0.001*	-40.000	-62.275	-17.726	26.982	<.001*	-42.815	-54.703	-30.928	46.316	<.001*	-40.204	-53.597	-26.811	49.61
pc 25	0.001*	-36.358	-56.649	-16.067	28.179	<.001*	-42.919	-53.901	-31.937	41.827	<.001*	-37.558	-49.631	-25.486	47.023
pc 75	<.001*	-41.926	-65.303	-18.55	31.721	<.001*	-44.233	-56.096	-32.371	121.772	<.001*	-40.267	-54.171	-26.364	133.265
VRP															
I-low	0.212	1.464	-0.921	3.849	16.593	0.129	-1.41	-3.242	0.422	56.565	0.580	-0.655	-3.050	1.741	28.243
I-high	<0.001*	16.407	11.436	21.378	23.963	<0.001*	9.167	5.042	13.293	29.523	0.004*	6.69	2.271	11.110	44.905
I- range	<0.001*	13.761	9.426	18.888	18.206	0.001*	10.53	6.354	14.742	47.681	0.002*	7.653	2.787	12.131	47.594
F-low	<0.001*	-34.664	-47.171	-22.156	16.296	<0.001*	-45.973	-55.182	-36.765	41.736	<0.001*	-38.178	-49.694	-26.663	35.682
F-high	<0.001*	200.711	109.547	291.875	17.841	0.046*	79.882	1.546	158.219	39.536	0.296	54.158	-49.437	157.753	34.280

F-range	<0.001*	239.011	148.369	329.653	19.397	0.003*	125.946	45.905	205.988	36.451	0.081	91.872	-11.996	195.740	34.396
Indices															
DSI	<.001*	3.092	1.639	4.545	46.415	<.001*	3.234	1.687	4.781	33.076	0.189	0.947	-0.485	2.379	39.604
AVQI	<.001	-2.321	-3.136	-1.506	32.561	<.001	-1.399	-2.053	-0.744	38.592	.0440	-0.685	-1.35	-0.02	50.64

Abbreviations: sp.: spontaneous; EMD: estimated mean difference; CI: confidence interval; df: degrees of freedom; pc: percentile; VRP: Voice Range Profile; I-low: lowest intensity; I-high: highest intensity, F-low: lowest frequency; F-high: highest frequency; DSI: Dysphonia Severity Index; AVQI: Acoustic Voice Quality Index; *: p<0.05

Table 4: VAS self-perception before and after glottoplasty

Self-perception	pre				post 1 week				post 1 month				post 6 months			
VAS	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Pitch	37	17	0	72	47	20	0	83	55	16	15	82	63	13	41	97
Femininity	33	18	5	67	46	19	9	85	58	17	19	84	67	16	42	100
Need for speech therapy	63	18	33	92	76	20	48	100	76	19	41	100	69	24	29	100
Higher voice post-op	.	.	.	.	53	26	0	98	61	28	16	100	82	16	56	100
More feminine voice post-op	.	.	.	.	54	25	0	96	68	23	18	100	84	15	60	100
More roughness post-op	.	.	.	.	84	17	49	100	77	18	26	100	61	27	0	100

Abbreviations: SD: Standard Deviation; min: minimum; max: maximum

Figures:

Figure 1: Listeners' perceptions of speaker gender before and after glottoplasty

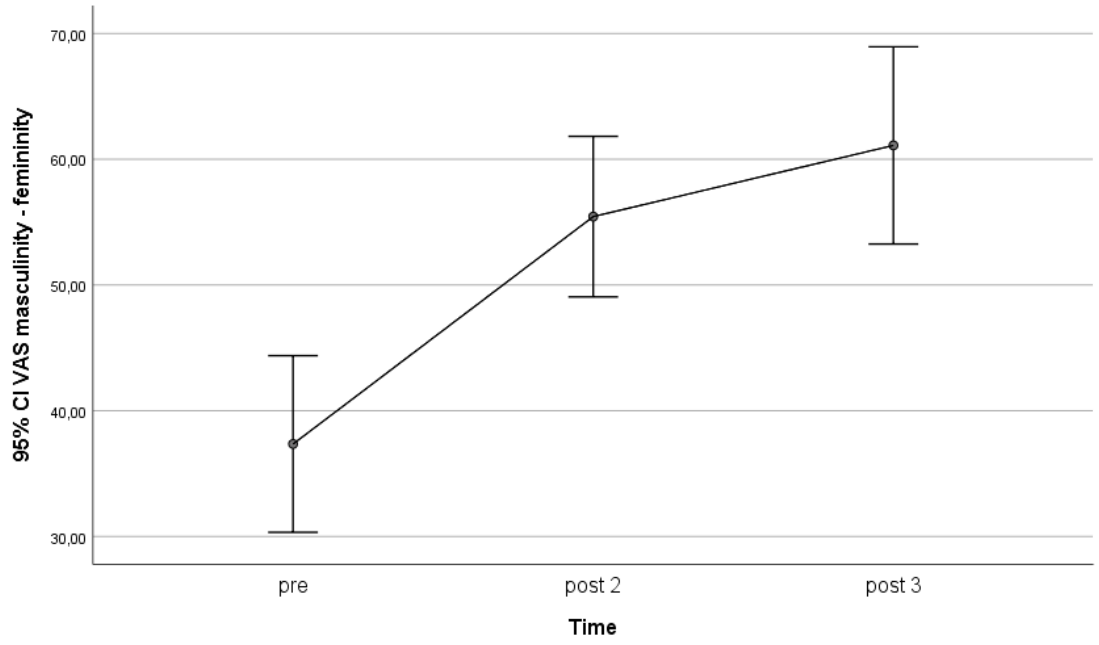


Figure 2: VHI scores before and after glottoplasty

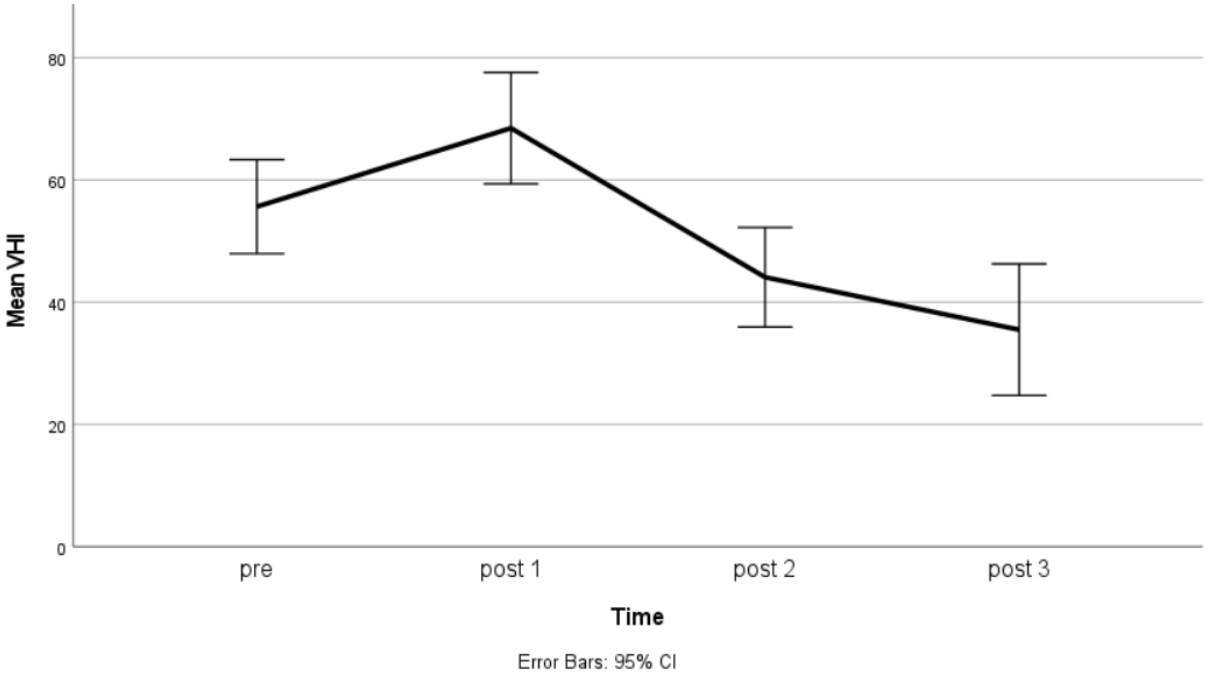


Figure 3: TWVQ scores before and after glottoplasty

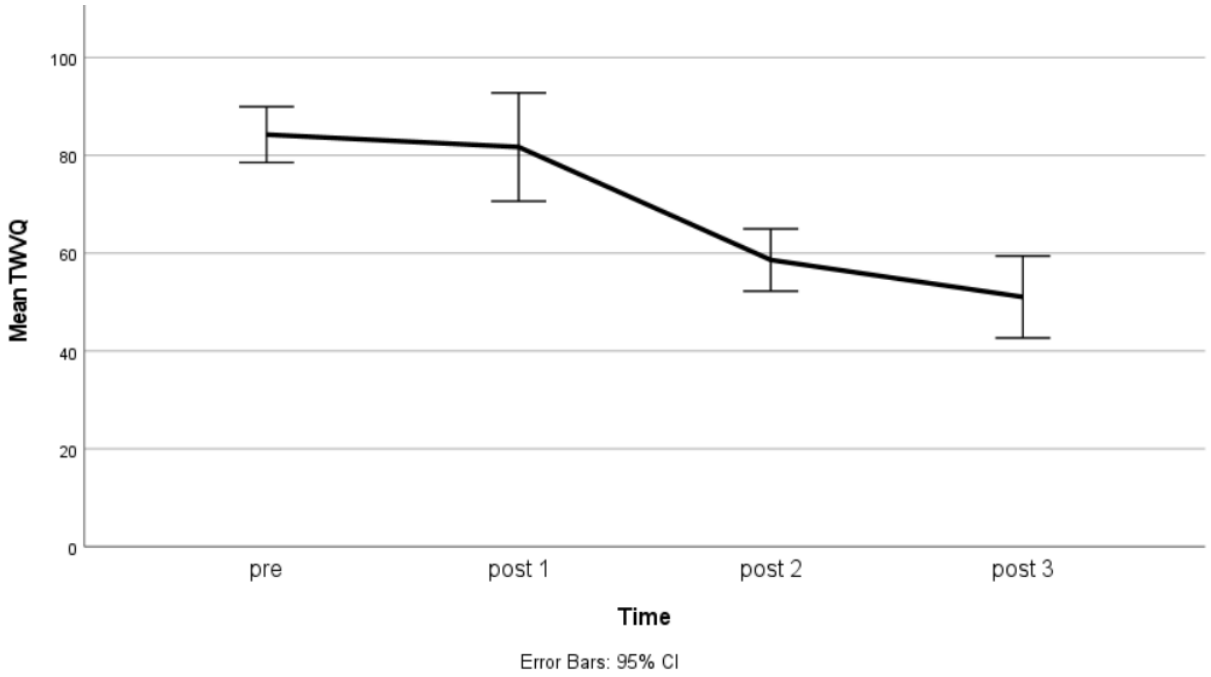


Figure 4: f_o changes over time in groups with and without voice therapy

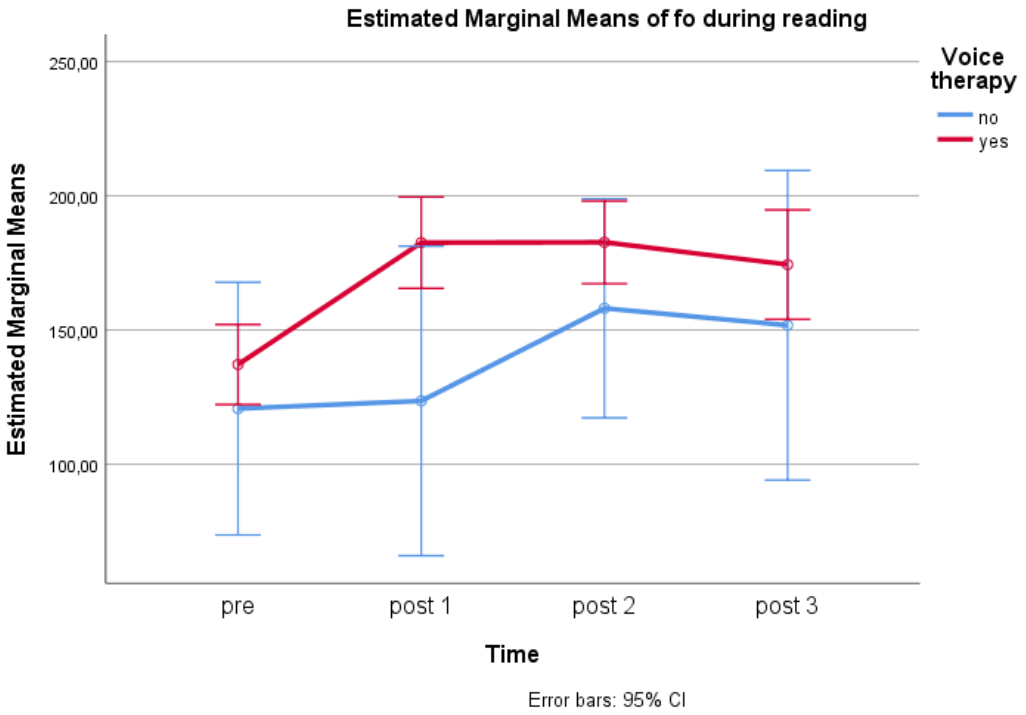
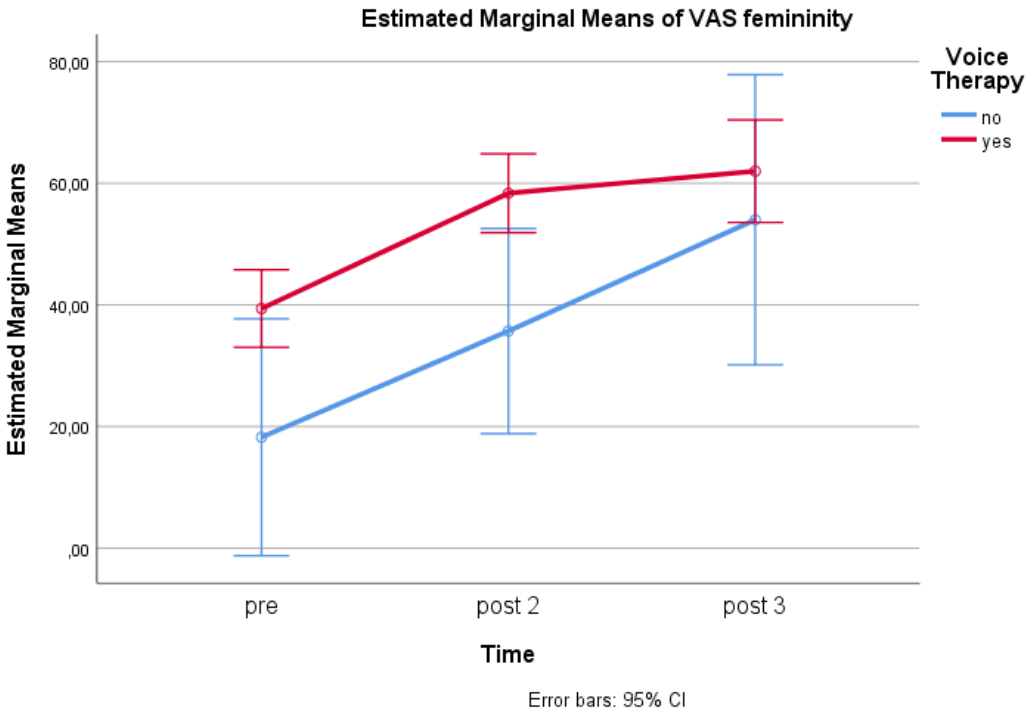


Figure 5: Listeners perceptions of speaker gender (VAS) over time in groups with and without voice therapy



Appendix A: VAS scales for client's satisfaction (translated in English)

How low/high is the pitch of your voice?

Very low neutral very high

How masculine/feminine is your voice?

Very masculine neutral very feminine

My voice sounds more feminine compared to my voice before surgery.

Completely disagree neutral Completely agree

My voice sounds higher compared to my voice before surgery.

Completely disagree neutral Completely agree

My voice sounds hoarse compared to my voice before surgery.

Completely disagree neutral Completely agree

I need speech therapy

Completely disagree neutral Completely agree

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