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Transmasculine voice modification: A case study

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Abstract

This case study measured the effects of manual laryngeal therapy on the fundamental frequency (f_o), formant frequencies, estimated vocal tract length, and listener perception of masculinity of a 32- year-old transmasculine individual. The participant began testosterone therapy 1.5 years prior to the study. Two therapy approaches were administered sequentially in a single session: (1) passive circumlaryngeal massage and manual laryngeal reposturing, and (2) active laryngeal reposturing with voicing. Acoustic recordings were collected before and after each treatment and three days after the session. Speaking f_o decreased from 124 Hz to 120 Hz after passive training, and to 108 Hz after active training. Estimated vocal tract length increased from 17.0 cm to 17.3 cm after passive training, and to 19.4 cm after active training. Eight listeners evaluated the masculinity of the participant's speech; his voice was rated as most masculine at the end of the training session. All measures returned to baseline at follow-up. Overall, both acoustic and perceptual changes were observed in one transmasculine individual who participated in manual laryngeal therapy, even after significant testosterone-induced voice changes had already occurred; however, changes were not maintained in the follow-up. This study adds to scant literature on effective approaches to and proposed outcome measures for voice masculinization in transmasculine individuals.

Keywords

transgender; transmasculine; voice therapy; case study research; laryngeal manual therapy; circumlaryngeal massage

1 Introduction

Transgender individuals experience incongruence between their gender identity and the sex assigned to them at birth. The mismatch of sex and gender identity may prompt the

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individual to seek services to alter various sex-specific characteristics. Voice is one such characteristic. Studies have shown that voice change is of great importance to transmasculine individuals[1] and that voice dissatisfaction may be present in a majority of this population.[2]

Transgender voice modification targets the voice and other aspects of communication to help the individual achieve congruence between voice and gender expression.[A] Voice modification services primarily have been offered to transfeminine individuals, given the limited-to-absent voice changes from estrogen during hormone replacement therapy (HRT) and the permanent laryngeal changes from testosterone exposure.[3–5] Conversely, transmasculine individuals undergoing HRT with testosterone often experience significant lowering of fundamental frequency (f_o).[6] Due to androgenic receptors on the vocal folds, they are sensitive to increased androgens such as testosterone.[7] Increased testosterone has been shown to cause hypertrophy of the thyroartyenoid muscle,[8] which makes up the main underlying body of the vocal fold. This increased mass and thickening of the vocal folds results in lower f_o, as is demonstrated during testosterone increases in cisgender male puberty.[3] Some transmasculine individuals therefore achieve congruence of voice and gender expression with testosterone HRT alone. However, this does not reflect the experience of all, as some transmasculine individuals may not wish to undergo testosterone HRT and some do not gain sufficient f_o lowering with testosterone alone. A meta-analysis of existing research on voice masculinization showed that incongruence of voice and gender expression may persist for as many as 21% of transmasculine individuals undergoing testosterone HRT.[9] In another study, 79% of transmasculine participants reported that they were not satisfied with their pitch after several months of HRT.[2] Further, a longitudinal study of trans men during testosterone treatment showed that 24% of the individuals reported negative voice symptoms after testosterone.[10]

Training techniques and goals for transmasculine individuals differ significantly from those of transfeminine individuals.[11] Thus, clinical recommendations for voice masculinization cannot be drawn from existing literature on transfeminine individuals. Yet there is little research on voice masculinization, with a particular lack of studies on the effectiveness of specific training techniques. Among the techniques used in transfeminine voice training is laryngeal manual therapy,[12] but its effectiveness in voice masculinization remains unknown.

Manual therapy has been used to treat a wide range of voice disorders and results in a lower resting position of the larynx and reduction in extrinsic muscle tension during phonation.[13–15] This technique, specifically the application of downward traction on the thyroid notch, has recently been shown to elicit f_o lowering in individuals with mutational falsetto.[16] Roy and colleagues[17] found that one session of manual laryngeal depression and functional lowering practice lowered mean f_o in cisgender male patients with mutational falsetto. A lower larynx results in lowered f_o by reducing vocal fold tension through rotation of the cricoid cartilage caused by cervical lordosis.[18] Lowering the larynx, and thus lengthening the vocal tract, has also been shown to reduce vowel formants.[19] Vowel formants are thought

[A]Care should be taken to differentiate between a speaker's gender identity (how they feel inside) and their gender expression (or presentation), which encompasses the way a person dresses, looks, and acts. Here we consider voice as an aspect of gender expression.

to relate to a listener's perception of gender, as speakers with lower vowel formants are more likely to be perceived as male.[20] Laryngeal manual therapy thus may be effective in simultaneously achieving two voice masculinization goals—the lowering of both f_o and vowel formants. The current study aimed to measure the effects of two types of manual laryngeal therapy on f_o, vowel formant frequencies, and listener perception of masculinity for a transmasculine individual who sought further masculinization of the voice after one and a half years undergoing HRT with testosterone.

2 Methods

2.1 Participant

The participant was a 32-year-old transmasculine individual (assigned female at birth). He had been taking weekly intramuscular injections of testosterone cypionate for 1.5 years at the time of recording. He was being followed closely by his primary care physician who had expertise in LGBT health. Following one year undergoing HRT with testosterone, his mean speaking f_o had lowered from 183 Hz to 134 Hz, and naïve listeners reliably rated his speech samples as male.[21] He was a heavy voice user and choral singer with no current voice quality or voice use complaints, but was interested in further masculinization.[B] He reported no history of speech or voice issues and had not previously completed any voice therapy. The participant completed written consent to participate, in compliance with the Boston University Institution Review Board as per protocol 2625.

2.2 Protocol

The participant completed one session of therapy, split into two parts: one passive and one active. He completed acoustic recordings at four different time points: before the session, following the passive therapy portion, following the active therapy portion, and three days following the therapy session to assess carryover. After the completion of the acoustic recordings on the day of the session, the participant and the clinician reviewed together their qualitative impressions of the treatment.

2.2.1 Recordings and stimuli—High-quality acoustic data were acquired in a sound-treated room using an omnidirectional earset microphone (MX153; Shure, Niles, IL) positioned at approximately 45 degrees from the midline and 7 cm from the corner of the mouth. Signals were preamplified by an RME Quadmic II (RME, Haimhausen, Germany) and sampled at 44100 Hz with 16-bit resolution using a MOTU UltraLite-mk3 Hybrid (model UltraLite3Hy; MOTU, Cambridge, MA). Recordings were made using Praat.[22] The participant was recorded producing prolonged low central vowel sounds (/ʌ/; four three-second productions), sixty seconds of spontaneous speech (e.g., describing his weekend, a recent holiday, an upcoming trip), Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) sentences,[23] and a reading passage (i.e., the first paragraph of the *Rainbow Passage*[24]). One set of recordings was obtained at each phase of treatment (baseline, post-passive, post-active, and follow-up).

[B]This is an important distinction that calls for clarification for the transgender population. Individuals may not have voice disorders or voice complaints as we might typically expect (e.g., no voice quality, loudness, or effort issues), but still may wish to pursue further masculinization or feminization.

2.2.2 Description of the treatment approach—Following baseline acoustic recordings, the participant was seated upright in an exam chair with the head resting against the headrest in a neutral position in relation to the shoulders. A speech-language pathologist specializing in voice disorders provided a primary palpation of the participant's paralaryngeal musculature and structures in order to identify their locus. The index finger and thumb of the clinician's dominant hand provided palpation via gentle pressing along the muscle bodies of the infrahyoid and accessory muscles (thyrohyoid, omohyoid, sternohyoid, sternothyroid, scalenes, trapezius, and sternocleidomastoid, bilaterally) as well as the suprahyoid muscle group (mylohyoid, stylohyoid, geniohyoid, and digastric muscle bellies).

The passive treatment portion of the session was then initiated. The participant was asked to refrain from voice use and to focus on breathing. A topical water-based lubricant was applied to the clinician's fingers and the participant's anterior neck surface. Elements of circumlaryngeal massage (CLM) and manual laryngeal reposturing were applied for a 16-minute period. CLM maneuvers were similar to those described first by Aaronson[25] and variations described in further laryngeal massage research.[26] First, the sternocleidomastoid muscles were gently massaged (2.5 minutes) using the index finger and thumb of the clinician's dominant hand with slow, downward pressure from the muscle insertion at the mastoid process to the origin at the sternum. Next, the thyrohyoid space was massaged bilaterally (3.5 minutes) with moderate pressure. The pressure was applied from the superior horn of the thyroid cartilage anteriorly along the superior aspect of the thyroid lamina to the superior thyroid notch. Next, the suprahyoid muscles were massaged (2.5 minutes) using a circular-shaped path starting anteriorly at the geniohyoid muscle, extending posteriorly along the superior aspect of the hyoid bone, descending to the thyrohyoid space, and massaging anteriorly in this space until reaching the geniohyoid muscles anteriorly and superiorly. After this, manual reposturing techniques were applied. Lateral dynamic stretches of the thyroid lamina (1.5 minutes) were performed using the index and middle fingers from both hands at a slow rate of about 1.5–2 seconds per lateral displacement. Following this, lateral static stretches of the thyroid lamina were completed (1 minute per side). Next, modified thyroid pull downs were administered (2 minutes) via downward traction on the superior border of the thyroid lamina with medial compression.[13] Finally, the hyoid pushback[13] maneuver was used (2 minutes), which involved medial and downward bilateral pressure over the greater horn of the hyoid bone. The amount of pressure applied during these maneuvers was greater than during initial palpation.

The participant then completed acoustic recordings following the above protocol, after which the active training portion of the session was initiated. The participant was asked to participate with vocalizations during various manual laryngeal reposturing techniques. Using a similar laryngeal lowering approach to Roy and colleagues,[14] the participant was asked to produce the vowels /a, e, i, o, u/ while the clinician administered various maneuvers to the larynx and surrounding structures. The techniques used were the hyoid pushback and the modified thyroid pull down as administered previously, with the goal of assisting with a lower laryngeal position during phonation and a clear, resonant voice with lower f_o. Medial pressure in the thyrohyoid space revealed a strained quality to the voice with an increased pitch, and thus was avoided. The most effective maneuver for obtaining a lower laryngeal position with target voice quality was the hyoid pushback technique, in which inward and downward pressure was applied to the hyoid bone. The clinician noted some laryngeal tensing in response to the clinician's digital depression. Thus, the participant was encouraged once to assume a yawn throat position and to relax his jaw. This effectively helped the participant to relax his larynx for increased clinician-applied depression. With further laryngeal depression, voicing practice continued until the voice was produced with increased oral resonance, decreased perceptual strain, and decreased pitch. The participant was encouraged to make note of the perceptual changes to the voice as well as the sensation of the throat in these different positions. Although the participant was unable to initially perceive the changes in the resonant characteristics of this voice, the treating clinician perceived auditory changes and provided feedback.

Once the target voice, as perceived by the clinician, was produced consistently, the participant was trained and encouraged to administer the maneuvers on his own larynx during the aforementioned vowel sequence without the manual depression from the clinician. The clinician then led the participant to continue this production into the /m/ sound, and moved through a hierarchy from isolated /m/ to /m/-initial syllables, words, phrases, and sentences. He was asked to produce stimuli both with and without the manual hyoid depression maneuvers in order to facilitate carryover of the target voice in the absence of digital manipulation. When the target voice was intermittently lost, he was asked to return to the prolonged /m/ sound as a reset or "basic training gesture," to facilitate motor learning of a target voice.[27] In order to facilitate improved motor performance and awareness of the target voice, he was also encouraged to use negative practice via intentionally alternating between his target and baseline voices.

After successfully producing the target voice with /m/-loaded words and phrases, the participant was asked to continue with various serial speech tasks including the days of the week, counting from 1 to 10, and the months of the year. After successful productions, he was encouraged to use his target voice during reading tasks and conversation. The participant demonstrated some difficulty at the spontaneous conversational level, requiring moderate cues from the clinician to use /m/ to assist with the production of the goal voice. He reported some difficulty in feeling a difference in laryngeal height outside of controlled speech tasks. After about 5 minutes of further practice in conversation, he independently self-corrected to produce a lower laryngeal position at the speech level. The total time of this second treatment portion was 20 minutes, after which the participant completed another set of acoustic recordings. The follow-up recordings occurred three days following the therapy session.

2.2.3 Perceptual study—Eight young adult listeners (4 cisgender females, 4 cisgender males; M: 20.0 years, SD: 1.9 years) evaluated the masculinity of the participant's speech productions during a single visit. All listeners were native speakers of American English who passed a hearing screening at 25 dB HL at octaves from 125 to 8000 Hz. No listener reported any history of speech, language, or hearing disorders. Listeners provided written consent in accordance with the Boston University Institutional Review Board.

The listener perception study was conducted in a sound-treated room at the study site. Recordings were presented via circumaural headphones (Sennheiser HD280 Pro). Listeners first heard two sample recordings from speakers other than the study participant (one cisgender female, one cisgender male). These samples were used to set the computer volume to a comfortable level for each listener; thus participants were instructed to listen to the recordings and adjust the volume as needed. Presentation order of these sample recordings was counter-balanced across listeners.

Experimental recordings were then presented to listeners in two groups. One group included excerpts from the reading passage (sentence 3 of the *Rainbow Passage*) as read by the participant at each time point of the study. The other included excerpts of spontaneous speech. Excerpts averaged 5.0 seconds (s) in duration (range: 4.3–5.9 s) and were normalized for peak intensity using MATLAB (Mathworks, Natick, MA). The order of these two groupings was counter-balanced across listeners. The presentation order of samples within these groups was randomized for each listener, as described below.

Listeners evaluated the participant's masculinity according to a paired comparisons method.[28] Listeners heard two recordings separated by a 250-millisecond, 500-Hz tone. They then selected the recording in which the speaker's voice sounded more masculine. They indicated their choice by clicking one of two boxes, which were labeled "first clip more masculine" and "second clip more masculine." All possible pairs of recordings (n=12) were presented twice in random order. That is, all permutations (e.g., baseline–post-passive, post-passive–baseline, baseline–post-active, post-active–baseline) were presented in a random order, and then presented again in a different random order, for a total of 24 paired comparisons per listener in each speech condition (reading passage and spontaneous speech). Listeners were allowed to play each pair of recordings once and recorded their responses using a custom-designed interface developed in MATLAB. The listening task lasted approximately 20 minutes.

2.3 Data analysis

2.3.1 Acoustic analyses—

Mean f_o was calculated in Hz using Praat.[22] A trained technician viewed the spontaneous speech samples[C] in Praat and exported pitch listings, which were evaluated further with custom MATLAB scripts.

Formants were extracted from prolonged productions of the low central vowel /ʌ/ by a trained technician using Praat. Formant frequency estimates were calculated over a steady portion of the vowel for four estimates per time point and averaged over those four productions. A low central vowel was chosen as the vocal tract most closely represents a tube with a consistent cross-sectional area, which makes it most appropriate for vocal tract length estimates.[29] The fourth formant was used to estimate vocal tract length in cm using Eq. 1, in which n is the formant number (4), c is the speed of sound in air (34,300 cm/s), and F_n is the measured formant location in Hz (approximating the fourth vocal tract resonance).[29]

[C]A variety of types of speech samples were gathered (sustained vowels, spontaneous speech, CAPE-V sentences), but the results were consistent across all tokens, so only spontaneous speech is discussed further.

$$\text{vocal tract length} = \frac{(2n-1)*c}{4*F_n} \qquad \text{Eq.1}$$

2.3.2 Perceptual analyses—Listener perception data were analyzed according to Thurstone's law of comparative judgment with Case V simplification.[28] Each stimulus has a scale value that situates the stimulus along a psychological continuum.[30] Here, the stimuli were voice recordings at each time point, and the psychological continuum corresponded to the perception of voice masculinity. A stimulus with a lower scale value was a voice perceived as less masculine than one with a higher scale value. Scale values were calculated based on the proportion of instances in which a stimulus was chosen as more masculine than another.[31,32] Scale values for the speaker's voice at each time point were calculated by individual listener and as an average across listeners. Intra- and inter-rater reliability were measured as percent agreement across presentations of each stimulus pair.[30]

3 Results

3.1 Clinician and patient-assessed outcomes

As per the CARE guidelines for case studies,[33] both clinician and patient-assessed outcomes were gathered. The participant initially reported some mild discomfort with different techniques, including the hyoid pushback and laryngeal pull down maneuvers. It was encouraged that the participant apply only the degree of pressure necessary to obtain the target voice but to avoid eliciting any compensatory laryngeal tensing during the training phase.

As reported in the methods, the participant demonstrated some difficulty at the spontaneous conversational level, requiring external cues from the clinician to produce the goal voice. He remained unable to feel or hear the difference in laryngeal height outside of controlled speech tasks, although he could perceive the lowered pitch. Although the treating clinician could hear and identify when he reached a "target voice," he remained unable to feel the correct laryngeal posture or identify the correct resonant characteristics of the target. Further therapy sessions would likely focus on his self-perception and identifying the somatosensory targets for his goal voice. He could, however, perceive the lower pitch of the target voice and agreed that it sounded more masculine.

3.2 f_o measures

Fundamental frequencies during and following the therapy session are shown in Figure 1. The participant's f_o changed following both the stages of therapy, passive circumlaryngeal massage/lowering and active manual laryngeal reposturing methods. During pre-therapy recordings, the participant's f_o was 124 Hz (SD: 18 Hz). Following the passive portion of the session, his f_o was 120 Hz (SD: 16 Hz), and following the entire therapy session, it was 108 Hz (SD: 10 Hz). In a follow-up recording, it had returned to slightly above pre-therapy levels (132 Hz, SD: 19 Hz).

3.3 Formants

Formant frequency estimates are shown in Figure 2 (left panel) for the first four formants, calculated over steady state vowels. Interestingly, unlike f_o, the formant frequency estimates were stable between the pre-session recording and following the passive portion of the session. They then lowered following the manual reposturing training. Formant frequency estimates returned to baseline levels in the follow-up session, suggesting that changes were not maintained.

Vocal tract length estimates are shown in Figure 2 (right panel). Vocal tract length remained similar from pre-session recordings (17.0 cm, SD: 0.26) and following the passive portion (17.3 cm, SD: 0.10). The vocal tract length was 19.4 cm (SD: 0.67) following the entire session, but returned to baseline levels (17.2 cm, SD: 0.12) by the follow-up session.

3.4 Perceptual study

Intrarater reliability was comparable for both stimulus types. Average percent agreement across repeated comparisons was 0.78 (range: 0.67–0.92, SD=0.10) for the reading passage recordings and 0.76 (range: 0.67–0.92, SD=0.09) for spontaneous speech. All listeners were thus considered sufficiently reliable for the perceptual task given that gender-related judgments are regarded as complex and changeable.[2] Interrater reliability, calculated as percent agreement across listeners, was 0.72 for reading passage recordings and 0.76 for spontaneous speech.

For both stimulus types, the participant's voice after active training was identified as more masculine than his voice at all other time points. The point at which the participant's voice was identified as least masculine differed by stimulus. With reading passage recordings, his voice at baseline was chosen as least masculine; with spontaneous speech, his voice after the passive portion of the session was chosen as least masculine, but just slightly less so than at follow-up. Scale values for the participant's voice at each time point are shown in Figure 3.

4 Discussion

4.1 Comparisons to the literature

Available research on voice training/therapy tasks for transgender individuals largely focuses on voice feminization tasks and exercises. Further, expert voice clinicians acknowledge the paucity of data on transmasculine voice.[2,11,12,34] To the knowledge of the authors, there exists no published research in which circumlaryngeal massage or manual laryngeal resposturing approaches have been studied specifically in transmasculine individuals. Furthermore, due to the paucity of transmasculine treatment research, current recommendations for voice modification in general are largely anecdotal. Given the abundance of research on the positive effects of these techniques in hyperfunctional voice disorders[13,15,19,35,36] and mutational falsetto,[14,16,17] the goal of this investigation was to apply the similar goal of laryngeal lowering to facilitate reductions in f_o, vowel formant frequency estimates, and vocal tract length in this population.

Roy and colleagues used a similar treatment approach in patients with mutational falsetto and found a mean f_o drop of 4.6 semitones during a reading task following laryngeal manual therapy.[17] This change was greater than that observed in our study (2.4 semitones), but was to be expected given the potentially larger degree to which patients with mutational falsetto speak outside of that expected for their laryngeal anatomy. The participant in the current study did not speak in falsetto register, and thus, it is expected that the treatment effects may be smaller when compared with this population. Conversely, studies using laryngeal manual therapies in patients with functional dysphonia have found no significant changes to f_o.[14,26] However, vowel formant changes have been measured after laryngeal manual therapy in patients with hyperfunctional voice disorders and have shown significant reductions, consistent with a lengthening of the vocal tract. Roy and Ferguson found a mean reduction in F3 from 2931.5 Hz to 2871.5 Hz, which would suggest a small lengthening of the vocal tract from 14.6 cm to 14.9 cm.[19] Formant frequency changes have also been shown to change in patients with mutational falsetto who receive manual therapy, where statistically significant changes have been observed in F1 and F2.[16] However, F1 and F2 are affected primarily by tongue position, whereas higher-order formant frequencies (e.g., F3 and F4) are more indicative of vocal tract length.[29] In contrast, the estimated vocal tract length of the participant in this case study underwent larger changes, from 17.0 cm (SD: 0.26) in pre-session recordings to 19.4 cm (SD: 0.67) at the end of the full session. These much larger differences thus may not be generalizable.

4.2 Listener perception of masculinity

Naïve listener reports may not capture the complexity of interactions and negotiations that contribute to the perception of masculinity. Each listener in this study brought a unique set of experiences—and assumptions informed by those experiences—into a task in which they actively judged the speaker's voice. The role these experiences and assumptions played on each listener's perceptions has not been explored here. Nevertheless, the perceptions these naïve listeners derived from voice samples represent a common type of interaction: brief exchanges with unfamiliar individuals by phone or other voice-only contexts. Such interactions can be of particular concern for a transmasculine individual whose voice may contribute to misattribution of gender identity or other characteristics by others. Thus, the experiences of transmasculine individuals in voice-only contexts are often explored in research and clinical practice[2] and are approximated in the perceptual experiment conducted here.

Changes in masculinity ratings across the time points in this study largely followed the pattern of changes in f_o and estimated vocal tract length. The participant's voice was perceived as most masculine at the end of the session, when f_o was lowest and estimated vocal tract length was greatest. Studies of cisgender and transfeminine voices have shown a strong link between f_o and perceptions of masculinity/femininity.[37–40] Whether this holds for transmasculine speakers is less clear. The present finding is not consistent with previous, albeit limited, research that found no correlation between f_o and perceptions of "maleness" in a cross-sectional study.[41] However, the present findings *within one* speaker do suggest a potential relationship between f_o, estimated vocal tract length, and perceptions of masculinity of transmasculine speakers that warrants further investigation.

4.3 Clinical implications

Given the wide range of techniques and exercises that exist for laryngeal manual therapy, multiple approaches could be taken to assist with laryngeal lowering. Various combinations of voicing, no voicing, kneading, massaging, and stretching could be implemented to target laryngeal lowering. The goal of our methods was to address the resting state of the larynx with and without phonation, to see the degree to which functional training with voicing further improved our participant's outcomes. Reduced f_o and lowered formant frequency estimates were appreciated after both treatments; however, these changes were greater after functional training with voicing. Further, these changes were not maintained in follow-up, despite incorporating elements of motor learning to assist with acquisition. Given the short exposure to this lengthened vocal tract and simultaneous f_o drop during treatment, it is likely that multiple, intensive therapy sessions with extended conversational practice may further promote carryover. Further, it is likely important to examine the individual's self-perception of their voice, and to assess whether there is any interaction between self-perception of the obtained voice and its carryover in follow-up. Given that laryngeal lowering was not part of the participant's habitual manner of voice production, initial carryover would likely depend on the volitional use of this attained voicing strategy. It is plausible that individuals who perceive their target voice with increased gender congruence may obtain improved carryover, but this hypothesis should be examined closely in future research.

These preliminary data suggest that laryngeal reposturing training with voicing provided a greater reduction in f_o and change in perceptions of voice masculinity over passive manual laryngeal techniques alone within our participant. Given that laryngeal height can be volitionally manipulated during voice production, it is plausible that behaviorally training a transmasculine individual to target a lower laryngeal position would further assist with its carryover into higher levels of speech production. Pitch is only one domain to address in voice masculinization therapy. Here, the therapeutic approach was also shown in this case study to change the resonant characteristics of the voice via a concomitant lowering of formant frequency estimates. Targeting laryngeal height and pitch simultaneously versus solely focusing on pitch lowering may facilitate resonance and pitch changes that have a greater synergistic impact on a listener's perception of masculinity. The targets of pitch and resonance are consistent with practice in the transfeminine population.[11]

Given the complexity and novelty of this task to an untrained speaker, it may be useful to initially work hierarchically (e.g., syllables, words, sentences, etc.) with training stimuli to lessen the cognitive load during the motor learning process. Similarly, our participant appeared to produce the target voice with greater accuracy when broad, extrinsic goals were encouraged (e.g., overall low feeling in throat, broad perceptual characteristics of the voice). Further, simultaneous principles based in motor learning theory were utilized as demonstrated in conversation training therapy,[42] in order to facilitate carryover and motor learning. These included negative practice, auditory and kinesthetic awareness of voice production, and use of a basic training gesture, /m/.[42] Roy et al.[17] used a similar approach to provide further awareness, proprioception, and vibrotactile sensations to associate with the target voice. It important to note that these therapeutic strategies and cues were used alongside laryngeal reposturing to facilitate learning and may have potentially impacted our results. The relative speed at which the participant was able to carry these over into speech in the session may not be representative of the average individual and an individual's own response to approaches should be monitored and treatment approaches adapted appropriately. However, it is possible that the incorporated broad learning approach assisted with increased speed of target accuracy in this case study.

This technique provided an immediate effect to the participant. Considering the participant did not maintain lowered f_0 or formant frequency estimates in the follow-up recordings, it is likely that multiple sessions would be needed in order to obtain retention and habitualization of a targeted lower laryngeal position, which is in line with general treatment protocols for voice disorders.[27,42–44] Further, since the exact mechanism of these techniques is not entirely clear, it is difficult to predict the length of treatment time needed for generalization. One potential hypothesis is that this individual and other transmasculine individuals may remain "locked" in higher laryngeal positions as a compensatory response to known vocal fold changes caused by HRT; if so, this therapy may be assisting with the normalization of the larynx via a lowering of its vertical height. Conversely, an alternative is that the participant and other transmasculine individuals may not have an elevated larynx at baseline, and thus, continued practice in lowering of the larynx may not be the most efficient voicing possible and may induce hyperfunctional compensatory patterns with long-term use. It is likely that both scenarios may exist among transmasculine individuals. Consecutive sessions of voice therapy would allow for analysis of the sustainability of the target voice given an individual's report of vocal effort and/or fatigue, as well as the clinician's perception of strain or other maladaptive phonatory behaviors. Consecutive therapy sessions might focus on maintaining a lower laryngeal position that feels sustainable, sounds authentic, and does not induce compensatory or hyperfunctional behaviors with long-term use. Further research beyond case studies would be welcomed to draw larger conclusions for the transmasculine population.

4.4 Limitations and future directions

A limitation of the current study was the single recording session at each phase of the study. While these were the appropriate length to gather a snapshot of vocal function at each point within a session in a clinical setting (e.g., each recording took around 10 mins), these may not represent an accurate picture of ongoing function. Future research may include multiple baselines as a means of obtaining a broader representation of baseline and post-intervention f_0 and formant frequency estimates. The participant's habitual f_0 three days post-therapy was 8 Hz (1 semitone) above his baseline amplitude. We assume that this represents a return to baseline rather than a negative result of therapy. However, multiple baselines would have allowed a clearer sense of the participant's typical variability. As this is a case study, we are unable draw conclusions as to the success of these techniques in other transmasculine speakers. Further studies with larger sample sizes are needed to determine the efficacy of manual laryngeal reposturing techniques in transmasculine individuals. Similarly, single-subject research designs may be useful to observe the effects of various approaches within an individual. These therapeutic techniques may be of particular interest to transmasculine individuals who have not taken or do not wish to take testosterone, or those whose voices do not become "sufficiently" masculine from HRT with testosterone alone. However, manual reposturing techniques effected measureable acoustic and perceptual changes in the voice of the participant in the short-term in this study, although he had already experienced substantial voice changes from undergoing HRT with testosterone. We also believe that the use of various facilitative techniques including negative practice, auditory and kinesthetic awareness of voice production, and use of a basic training gesture, /m/, may have affected our results, as these techniques were used to facilitate the targeted laryngeal reposturing. Finally, given that our treatments were serial in nature, it is possible that the initial passive circumlaryngeal massage therapy assisted the outcome of the subsequent resposturing with voicing, and thus, future studies may provide both treatments at different time points to greater assess their respective individual effects.

5 Conclusions

In this study, we evaluated the effects of a single session of behavioral voice therapy with a transmasculine speaker, following techniques developed for hyperfunctional voice disorders and mutational falsetto. Laryngeal reposturing appears to immediately and simultaneously affect pitch and resonance by reducing f_o and decreasing vowel formant frequency estimates through an elongation of the vocal tract. While passive circumlaryngeal massage and manipulation techniques without voicing resulted in a somewhat lowered f_o and formant frequency estimates, recordings following the active segment of the session showed the greatest effects, both acoustically and perceptually. Thus we conclude that the manual laryngeal reposturing with active voicing and client participation seems to be an important component of the therapy session. Although this is a case study, we conclude that behavioral training via manual laryngeal reposturing techniques with active voicing may be an effective technique in behavioral voice masculinization and should be explored further in the transmasculine population.

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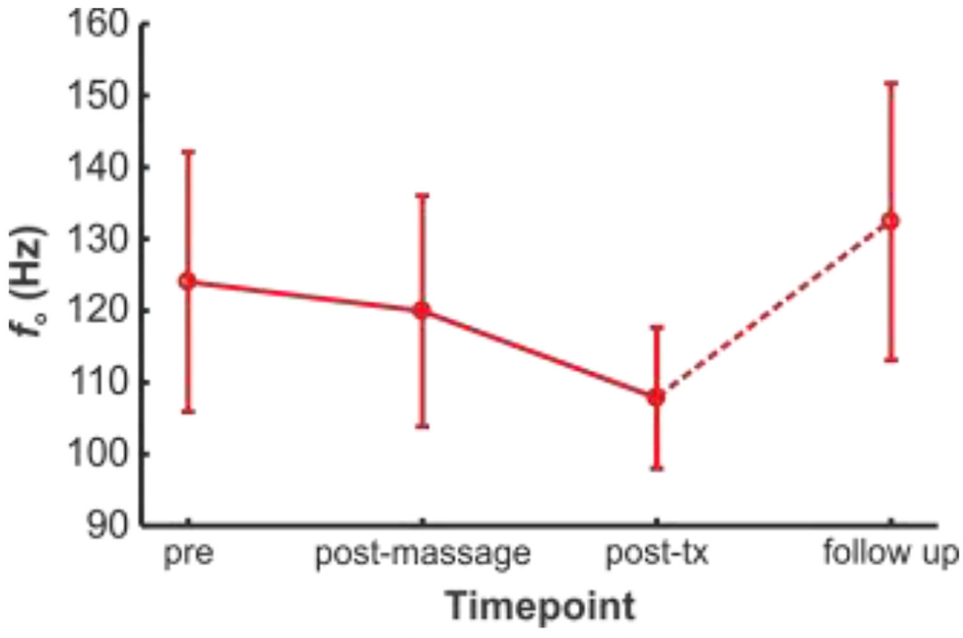

Figure 1.

Fundamental frequency (f_0) during spontaneous speech for three time points during the session (pre-intervention, post-massage, post-therapy) and the follow up session (three days after). Error bars are f_0 standard deviations (correlate of intonation).

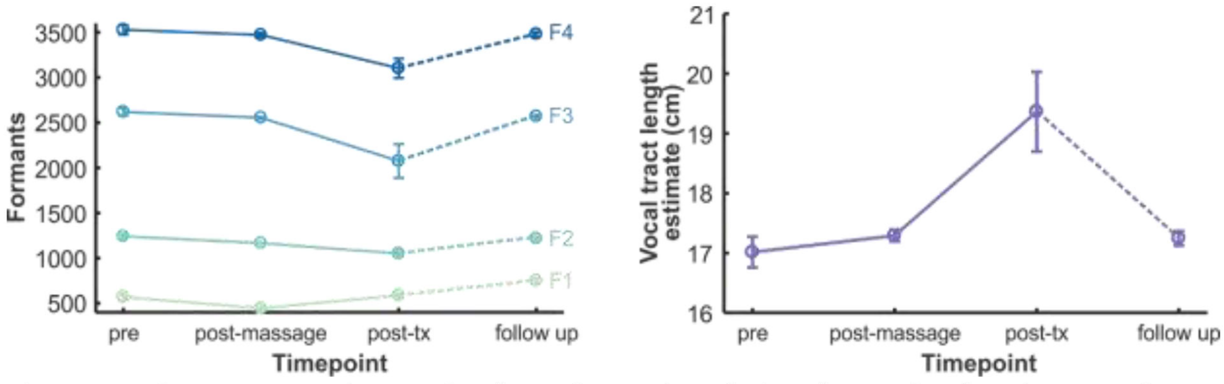

Figure 2.
Left: Formant estimates for three time points during the session (pre-intervention, post-massage, post-therapy) and the follow up session (three days after). Right: vocal tract length estimates based on F4. Error bars indicate standard deviations.

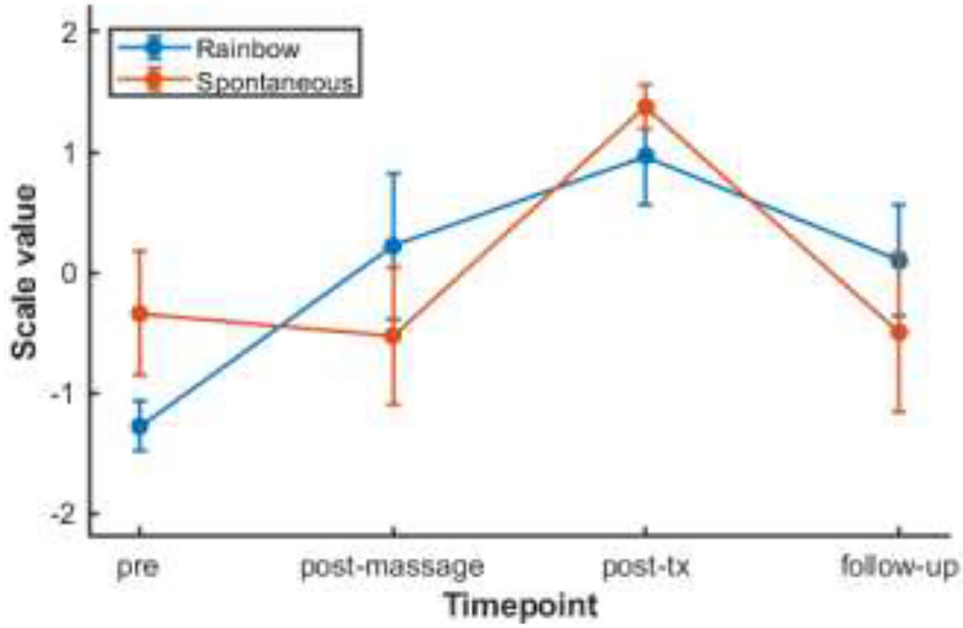

Figure 3.

Scale values of perceived voice masculinity for the participant's voice at each time point in the study. Error bars are standard deviation across listeners. Higher scale values correspond to the perception of greater masculinity.