# Acoustic and Perceptual Effects of Articulation Exercises in Transgender Women

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## Abstract

**Purpose**: This study measured the impact of articulation exercises using a cork and articulation exercises for lip spreading on the formant frequencies of vowels and listener perceptions of femininity in transgender women.

**Methods**: Thirteen transgender women were recorded before and after the cork exercise and before and after the lip spreading exercise. Speech samples included continuous speech during reading and were analyzed using Praat software. Vowel formant frequencies (F1, F2, F3, F4, F5) and vowel space were determined. A listening experiment was organized using naïve cisgender women and cisgender men rating audio samples of continuous speech. Masculinity/femininity, vocal quality and age were rated, using a visual analogue scale (VAS).

**Results**: Concerning vowel formant frequencies, F2 /a/ and F5 /u/ significantly increased after the lip spreading exercise, as well as F3 /a/, F3 /u/ and F4 /a/ after the cork exercise. The lip spreading exercise had more impact on the F2 /a/ than the cork exercise. Vowel space did not change after the exercises. The fundamental frequency ($f_o$) increased simultaneously during both exercises. Both articulation exercises were associated with significantly increased listener perceptions of femininity of the voice.

**Conclusions**: Subtle changes in formant frequencies can be observed after performing articulation exercises, but not in every formant frequency or vowel. Cisgender listeners rated the speech of the transgender women more feminine after the exercises. Further research with a more extensive therapy program and listening experiment is needed to examine these preliminary findings.

**Keywords**: transgender voice, transgender women, effectiveness, articulation, speech therapy

## Introduction

The adjective ‘transgender’ relates to people who experience their gender identity non-conformant with the sex assigned at birth. This may lead to gender dysphoria [1-3]. One hurdle experienced by transgender people is that voice, speech and communication may not be congruent with their gender presentation and identity, which negatively impacts integration in society and psychosocial functioning [4, 5]. A study by Hancock, Krissinger [6] showed that quality of life scores of transgender women (male-to-female transgender persons) were higher the more their voice was perceived as feminine. Since gender affirming hormone treatment does not affect the voice in transgender women, voice and communication training is the intervention of choice to develop a more feminine communication [7-10].

Feminization of the voice during voice and communication training includes both prevention of vocal hyperfunction [11] and adjustment of several voice characteristics such as speaking fundamental frequency, fundamental frequency range, intonation patterns, loudness, vocal quality and resonance [12, 13]. Voice and communication training may focus on aspects of communication that are most salient in listener perceptions of speaker gender [14]. Results of a systematic review and meta-analysis by Leung, Oates [15] showed that those aspects are primarily fundamental frequency ($f_o$) of the voice and secondly resonance characteristics. The results of this systematic review with meta-analysis suggested that the $f_o$ of the voice contributes for 41.6% of the variance in gender perception. This percentage suggests that listeners' perceptions may not change from male to female or masculine to feminine by altering pitch alone.

Leung, Oates [15] reported resonance as the second most widely studied vocal domain concerning listener perceptions of speaker gender. A study by Hardy, Boliek [16] found that besides fundamental frequency, vowel formant frequencies were identified as significant predictors of masculinity–femininity ratings. Resonance depends on the length and shape of the vocal tract which can be altered to change the frequencies of the vowel formants [17, 18]. Formant frequencies of vowels depend on the dimensions of the vocal tract. The larger the cavities, the lower the formants; and vice versa [19-22]. Average formant frequency values for cisgender males are twenty percent lower than those of cisgender females [23]. Vowel space is calculated using the first two formants [24] and subsequently, vowel space is larger in cisgender women than in cisgender men [25]. A study by Coleman [26] demonstrated that the difference is caused by smaller female physical dimensions of the cavities of the head and neck compared to cisgender men. However, another study by Günzburger [27] mentioned that the differences in formant frequencies are too large to be generated by merely anatomical characteristics. The author proposed that people modify their vocal characteristics to comply with either female or male speech stereotypes. A study by Oates and Dacakis [28] for example, confirmed that on average, cisgender women articulate more precisely and accurately compared to cisgender men. Cartei, Cowles [29] asked 17 cisgender men and 15 cisgender women to imitate the voice of the opposite gender. These imitations were compared with the pre-test measurements in terms of $f_o$, formants 1 (F1), 2 (F2), 3 (F3) and 4 (F4) and the degree of lip spreading and mouth opening. When asked to imitate masculinity, formant frequencies dropped, inducing a smaller vowel space. The opposite happened when imitating female voices. Additionally, a significant difference in lip spreading was found with female voices showing a larger lip spreading than male voices on average. Although no statistically significant differences were found, mouth opening, a key determinant of F1, was found to be larger in cisgender women compared with cisgender men. Moreover, cisgender women were found to have a larger vowel space which might be associated with a perceptual femininity of the voice [30].

Weirich and Simpson [30] also showed that the lower the first formant frequency, the more masculine a voice is judged. The frequency of the first 4 formants have been empirically shown to contribute to gender perception [15, 31]. Higher formant frequencies contribute to the perception of a female speaker. A listening experiment conducted by Pisanski and Rendall [32] showed that listeners use formant characteristics as a cue to gender attribution. Gallena, Stickels [33] investigated gender perception of the voice after increasing both the $f_o$ and formant frequencies. If the $f_o$ is in the gender ambiguous zone (150 Hz – 185 Hz, Mordaunt [34]), the voice of transgender women is nevertheless often perceived as that of cisgender men when the formant frequencies are still in the male area. A minimum increase of 20% of all formant frequencies and the resulting increase of vowel space results in a statistically significant increase of perceiving a voice as female or feminine. For a single formant frequency to be perceived as not-male by most listeners in the experiment, its frequency needed to be raised to 80%–100% of cisgender female formant frequency averages. Therefore, it would be more effective to aim at a moderate increase of all relevant formant frequencies and vowel space [33].

In order to change the female gender perception for transgender women, it is important to examine vowel characteristics, formant frequencies and larynx height. Vowel characteristics can be described as jaw drop or mouth opening, lip spreading, tongue position and duration of the vowel [35]. The first three characteristics play a role in adjusting the resonance of the voice and determine the frequencies of the first three formants. Ladefoged [36] mentioned that first formant (F1) is inversely related to vowel height. If the tongue position lowers during the production of vowels, F1 increases. According to Corthals [24], the F1 is related to the jaw drop (larger jaw angle induces a higher F1). Mount and Salmon [37] correlated F2 to the degree of fronting of the tongue, meaning, a more forward tongue position induces a higher F2, which was confirmed by Corthals (2008). Günzburger [27] and

Corthals (2008) concluded that F3 increases considerably when there is less lip protrusion and when the oral cavity is shortened by elevating the tongue and larynx. These elements determine the frequencies of the vowel formants and will therefore have an impact on resonance. Less is known concerning physiological correlates of F4 and F5. A study by Fant [38] confirmed that the laryngeal cavity has an important influence on both F4 and F5. Sundberg [39] reported that F4 in particular, but also F5, of sung vowels /a/ and /i/ are highly sensitive to the area function of the laryngeal cavity. Later, a study by Fant and Båvegård [40] demonstrated that F5 and F4 greatly increased after shortening the laryngeal cavity by 0.5 cm. Takemoto, Adachi [41] explained that F4 is provided almost only by the laryngeal cavity and therefore, the formant is mainly sensitive to the laryngeal cavity shape. There is a lack of studies that investigated the effect of manipulating vocal characteristics on F4 and F5.

Altering the tongue placement, which influences F2, can also be related to articulatory precision. Free and Dacakis [42] provided insight into the influence of articulatory precision on the perception of gender in the speech of transgender women. Participants provided two reading samples of the Rainbow Passage [43], one spoken with precise articulation and the second sample spoken with imprecise articulation (omissions, reductions and distortions of sounds). Eight of the 20 participants were rated as female more often when speaking with precise articulation. In addition, the speech of 15 of the 20 participants was considered more representative of a female speaker when using precise articulation.

Although therapy goals can be identified based on the systematic review of Leung, Oates [15], it is not yet clear whether voice and communication training focusing on these goals is successful, i.e. transgender women sound more feminine after the intervention and are satisfied with the outcome. Research on these intervention outcomes for transgender people is limited. De Bruin, Coerts [44] suggested that increasing pitch should be combined with the pursuit of a more forward vocal resonance. According to Schneider and Sataloff [45] vocal resonance refers to the way sound is shaped acoustically as it travels through the vocal tract. Head resonance, in contrast to chest resonance, is very important because this aspect gives the voice a highly feminine character [44]. Preliminary results of pilot studies in transgender women are promising and suggest that voice and communication training could result in vocal changes and gender perception [14, 46-51]. However, the results of these studies are difficult to interpret due to methodological issues such as retrospective study designs [8, 14, 48], small samples sizes [14, 46, 49-52], heterogeneous study populations [48], vaguely described therapy contents [14, 48], onedimensional approaches of voice assessment [14, 48, 49, 51] and risk for experimenter bias [14, 46, 48-52].

Carew, Dacakis [46] used oral resonance therapy to feminize the voice of transgender women. Intervention focused on lip spreading and forward tongue position. F3 in particular rose noticeably by applying lip spreading to reduce the oral resonance space. $f_o$ also increased by 30 Hz, even though this was not the objective. This finding showed that also $f_o$ can rise if the intervention focuses on resonance; it may have been the result of co-occurring laryngeal muscle tension during lip spreading and tongue placement assignments. Trends in the data suggested that the oral resonance therapy administered during this study was associated with increased listener perceptions of femininity of voice for the majority of participants.

The aforementioned study by Free and Dacakis [42] supplied initial support for the reduction of imprecise articulation in transgender women and De Bruin, Coerts [44] mentioned that a more explicit articulation with a decrease in lip rounding is an objective to feminize the voice. Lindblom [53] and Searl and Evitts [54] showed that clear speech causes an increase in the overall effort of speech production. It results in some acoustic changes such as decreased rate of articulation, increased vowel duration, and longer and more frequent pauses [55-60]. Other studies reported an increase in vowel space and extent of formant movements [55, 56, 61, 62]. Additionally, clear speech demands speakers to increase articulatory precision with the production of precise, explicit consonants and to focus on the kinesthetic feedback of the oral sensations from the consonants. This centralized focus on the external effect of a gesture enhances learning, as well as efficient phonation [63]. Skrabal, Tykalova [64] reported that there is a positive association between these acoustic alterations and increased clarity [65], intelligibility [66, 67] as well as movement size of the articulators including the jaw, tongue blade and tongue dorsum (Kearney et al. 2017). The cork exercise aimed at forward and larger articulation movements during phonation by training the awareness of the mouth muscles [68]. These forward articulation movements, which focuses speech in front of the mouth,  target oral forward resonance [69]. According to Carew, Dacakis [46], Erickson [70], Ladefoged [36], Corthals [24] and Mount and Salmon [37] F1 and F2 might correlate with the degree of jaw opening and tongue position, due to articulatory precision. The cork exercise could therefore be a potential exercise to increase jaw drop and articulatory precision [71, 72], which might influence gender perception [73]. However, the effects of separate exercises using cork and lip spreading on the formant frequencies and on the listener perceptions have not been investigated yet.

The aim of this study was to measure and compare the impact of both the cork and lip spreading exercise on acoustic outcomes, including formant frequencies, fundamental frequency and vowel space, and on gender perceptions in a group of naïve listeners. It was hypothesized that the lip spreading exercise would increase F3 values as indicated by Carew, Dacakis [46] and that the cork exercise would increase F1 and F2 values due to larger articulation movements [68]. Both exercises would increase vowel space. Concerning listener perceptions, a higher perception of femininity was hypothesized after both exercises.

## Methods

This research project was completed according to the Declaration of Helsinki and approved by the Ethics Committee of the Ghent University Hospital with the following registration number: B670201938698. A written informed consent was signed by each participant.

### ***Participants***

#### *Transgender Women*

Thirteen transgender women were included in the study. They were recruited through the Gender team of the Ghent University Hospital (Belgium). All participants had received pitch elevation training prior to the study, but had not yet received any articulation training to feminize the voice. The pitch elevation training included: 1. targeting a higher pitch in isolated nasal consonants (approximately till 160 Hz), 2. adding consonant-vowel-consonant combinations, 3. using gliding tones from habitual pitch to the 'new' pitch (also with a resonance tube in water, i.e. LaxVox), 4. word level, 5. automatic speech, 6. sentence level, 7. text level and 8. spontaneous speech. Inclusion criteria were an established diagnosis of gender dysphoria and female gender identity confirmed by the interdisciplinary Gender team at the Ghent University Hospital, (Belgium), age between 18 and 70 years, self-reported normal hearing, Dutch speaker, with gender affirming hormonal treatment (confirmed by blood analysis) and a female gender role. Exclusion criteria were: a history of neurological disorders, previous phonosurgery or voice and communication training focusing on articulation or resonance, pathology of the vocal folds (observed by videolaryngostroboscopic examination of the vocal folds), or smoking. Participants who smoked in the past, but quit at least 1 month prior to the start of the training were not excluded. In this study, none of the participants had a history of smoking. To form a homogeneous study population, gender nonbinary persons were not included. Age of the participants ranged from 24 to 67 years, with a mean of 40 years (SD: 14.2).

*Cisgender Speakers*

Ten cisgender speakers (5 cisgender men, 5 cisgender women) were included in the listening experiment. The ages of the cisgender speakers ranged from 24 to 66 years, with a mean age of 44 years (SD: 14.5). These speakers were recruited through word of mouth and were all native Dutch speakers. The speakers had a self-reported normal hearing, i.e. when asked about their hearing, they acknowledged this to be normal.

*Cisgender Listeners*

Twenty-two cisgender listeners (11 cisgender men, 11 cisgender women) ranging from 20 to 67 years, with a mean age of 43 years (SD: 16.4) and with self-reported normal hearing were recruited as naïve listeners through word of mouth. When asked about their knowledge of speech language pathology, the listeners declared that they had no prior education or experience in this topic. They were all native Dutch speakers and were blinded to the purpose of the study and the gender(identity) of the participants. The participants were told that 'they were going to listen to a few speech samples and evaluate age, vocal quality and femininity/masculinity'.

***Study Design***

[Figure 1 near here]

This study used a cross-over design (figure 1) and participants were randomly assigned to a group. Group 1 started with the lip spreading exercise, followed by the cork exercise, and group 2 were taught the same exercises but in the inverse order. There was an interval between the exercises of at least one week without any other therapy interventions.

***Speech Interventions of Speech Exercises***

All participants performed the cork exercises and lip spreading exercises in a sound treated room at Ghent University Hospital. The interventions were carried out by a certified and experienced speech language pathologist during a session of 30 minutes (i.e. one technique per session). During the cork exercise the participants used a cork with a diameter of 23 mm and length of 45 mm. They were instructed to place the upper front of the cork (approximately 2-3 mm) between their front teeth and to read words out loud with large and precise articulation movements (figure 2). After a fixed block of ten long nouns (6-9 syllables), they removed the cork and used the same large articulation movements to pronounce the same block of 10 words. This process was repeated for twelve blocks of ten words. Firstly with the cork between their teeth, afterwards without the cork. Lastly, participants were instructed to read the Dutch phonetically balanced text "Papa en Marloes" [74] with and without the cork. This text consisted of 70 words, divided in eight sentences, with a total duration of 20.9 seconds on average. Lip spreading therapy (figure 3) included a contrast exercise of spreading and rounding the lips without phonation and with phonation (i.e. the production of the vowels /u/ - /i/). Afterwards, lip spreading was encouraged while reading the exact same blocks of words as in the cork exercise as well as the phonetically balanced text. No instructions were given concerning the pitch during reading.

[Figure 2 & 3 near here]

***Data Collection***

*Speech Assessment*

The speech samples of the transgender women were recorded pre and post every therapy session of 30 minutes in a speech lab at Ghent University Hospital with a Samson C01U Pro USB Studio Condenser Microphone, digitized at a sampling rate of 44.1 kHz. The mouth-to-microphone distance was 15 cm during every recording, pre and post therapy. The calibration procedure of Maryn and Zarowski [75] was used to calibrate the microphone. This consisted of comparing the dB intensity levels of the microphone and a sonometer after recording white noise, resulting in a calibration factor which can be used for acoustic analyses. The samples were recorded using the Praat software program for acoustic analysis (Institute of Phonetic Sciences, University of Amsterdam, The Netherlands [76]). It contained continuous speech, i.e. a phonetically balanced text "Papa en Marloes" [74], including six /a/ vowels, two /i/ vowels and two /u/ vowels. For the post measurement the participants were instructed to read the text a second time, during which they were stimulated to use the taught articulation technique.

*Acoustic Analysis*

The speech samples were acoustically analyzed using the Praat software program [76]. Median $f_o$ and speech rate of the text was calculated and vowels /a/, /i/ and /u/ were manually extracted from the continuous speech ("Papa en Marloes"), using the 'View and Edit' and 'Annotate' pane. In order to capture vowel samples which were sufficiently long enough to perform acoustic analyses, the samples were concatenated into one sound chain per vowel with a mean duration of 0.2 seconds (SD: 0.14). Vowels /a/, /i/ and /u/ were selected as they stand for extreme tongue and lip positions during the production of speech. Formant frequencies (F1 – F5), vowel space ($Hz^2$) and formant contrasts (F2 contrast /i/-/u/, F1 contrast /a/-/i/, F1 contrast /a/-/u/, in Hz) were calculated from these vowel chains.

*Listening Experiment*

A listening experiment was conducted in a quiet room using a Dell Latitude 5590 laptop running Windows 10 and E-Prime software [77], and Marshall Monitor over-ear headphones. The first two sentences and the last sentence were cut from the phonetically balanced text ("Papa en Marloes") in order to keep a reasonable duration of the experiment. The remaining five sentences text with a mean duration of 16.4 seconds were selected as speech sample for this experiment. Twenty speech samples of cisgender men and women (2 samples per cisgender speaker) were incorporated to distract the listeners from the objective of the study in order to avoid biased answers as much as possible. Consequently, listeners had to rate 70 speech samples in total. Twenty-two cisgender listeners rated the samples during a listening experiment. The anonymous samples were presented in random order during one single visit at a comfortable intensity level, i.e. samples were presented at 30% of the maximum intensity level and listeners were able to adjust this level. The listeners were instructed to rate the speech samples for femininity/masculinity on a visual analogue scale using the anchors 'very masculine' (left side), 'very feminine' (right side), and 'neutral' in the middle. The listeners were instructed to treat the middle of the scale as ambiguous or neither feminine nor masculine. In order to distract the listeners from the objective and avoid biased answers, two extra questions (rating vocal quality and age on a visual analogue scale) were included in the experiment. The results of the two extra questions were not analyzed and were only used to prevent listeners from identifying the objectives of the study. The experiment lasted 40 minutes, during which after the first half, listeners had a five minute break as needed to maintain focus before completing the second half.

### *Statistical Analysis*

SPSS 25.0 (SPSS Corp., Chicago, IL, USA) was used for the statistical analysis of the data. In order to calculate the impact of each individual exercise, pre and post measurements were compared using a Wilcoxon matched-pairs signed-ranks test. In order to evaluate whether the lip spreading exercise had a higher impact than the cork exercise, new variables were computed to represent the impact of each exercise. The new variables expressed the difference post-pre measurements. These computed variables were analyzed through a Wilcoxon matched-pairs signed-ranks as well. The order effect of the exercises was determined using a Mann-Whitney U test. A Pearson correlation coefficient was computed to assess the relationship between the perceptual effects measured during the listening experiment and both the differences in $f_o$ and speech rate, calculated separately. Analyses were conducted at $\alpha = 0.05$. Inter-rater reliability was calculated for the listener experiment by means of two-way mixed ICCs, type consistency (single measures). ICCs were interpreted following the classification of Altman [78] (ICC < 0.20: poor, 0.21–0.40: fair, 0.41–0.60: moderate, 0.61–0.80: good, 0.81–1.00: very good).

## Results

### *Acoustic Analysis*

The results of the acoustic parameters before and after the lip and cork exercise are presented in table 1. $f_o$ was significantly higher after both the lip spreading and cork exercise (respectively p = 0.006 and p = 0.039). Concerning the formant frequencies, significantly higher values were observed after the lip spreading exercise for F2 and F5 (F2 /a/, p = 0.012; F5 /u/, p = 0.041). After the cork exercise, formant frequencies were significantly higher for F3 and F4 (F3 /a/, p = 0.046; F3 /u/, p = 0.023; F4 /a/, p = 0.023). No significant findings were reported regarding vowel space and contrasts between formant frequencies. The results concerning vowel space are presented in figure 4 and 5 (median values pre lip – post lip: 133.57-116.21 $Hz^2$; median values pre cork – post cork: 172.47-152.41 $Hz^2$). Normative values for cisgender women and men are also presented on figure 4 and 5 [79]. Comparing the impact between both exercises, calculated by the new variables which represent the difference post-pre measurements, only F2 during vowel /a/ increased significantly more as a result of the lip spreading exercise compared to the cork exercise. A Pearson correlation coefficient was computed to assess the relationship between the differences in $f_o$, speech rate and the perceptual effects measured during the listening experiment. For $f_o$ and the perceptual effects, there was a non-significant moderate positive correlation concerning the lip spreading exercise ($r = 0.540$, $p = 0.070$) and a non-significant negligible positive correlation concerning the cork exercise ($r = 0.249$, $p = 0.412$). Concerning the speech rate and the perceptual effects, a non-significant negligible negative correlation was found during the lip spreading exercise ($r = -0.079$, $p = 0.806$), and a non-significant low positive correlation during the cork exercise ($r = 0.394$, $p = 0.183$) [80].

[Figure 4 & 5 near here]

[Table 1 near here]

### ***Listening Experiment***

#### *Listener Perceptions*

Results regarding the inter-rater reliability are provided in table 2. Inter-rater reliability of the naïve listeners during the listening experiment was found to be good.

A group of naïve cisgender women and cisgender men rated the participants significantly more feminine after lip spreading ($p = 0.015$) and cork exercises ($p = 0.007$). Listeners rated the participants 40% more feminine after the lip spreading exercise and 29% after the cork exercise. Descriptive statistics and p values can be found in table 3.

[Table 2 near here]

[Table 3 near here]

### *Order Effect*

Participants were randomly assigned to one of two groups. The first group started with the lip spreading exercise and the second group started with the cork exercise. Statistical analysis showed that there was only one variable that differed significantly between both groups, being F2 during vowel /a/ ($p = 0.028$). Starting with the lip spreading exercise caused a higher impact of the lip spreading exercise on the F2 of /a/.

## Discussion

This study investigated the effectiveness of the lip spreading and cork exercise on acoustic outcomes and perceptions of voice femininity in transgender women. It was hypothesized that the lip spreading exercise would cause higher F3 values as lip protrusion is correlated with F3. Higher F1 and F2 values would be initiated by the cork exercise due to training larger articulation movements during this exercise, such as jaw drop and a more forward tongue position.

During this study, several significant changes in outcome parameters were measured. The lip spreading exercise caused a higher F2 during /a/ and a higher F5 during /u/. The cork exercise on the other hand caused higher F3 values during /a/ and /u/ and higher F4 values during /a/. No significant changes were found for the other formants or vowels. These results do not confirm the aforementioned hypotheses. Previous studies have shown that F1 is correlated with jaw opening or tongue height, F2 with the degree of fronting of the tongue and F3 with lip protrusion [24, 27, 36, 37, 79, 81, 82]. This means that the lip spreading exercise might induce a more forward tongue position during vowel /a/, resulting in higher F2 values. The cork exercise on the other hand showed more lip spreading during vowels /a/ and /u/, demonstrated by the significant increase of F3. Due to bigger articulation movements during the cork exercise, lip spreading might be implicitly encouraged during this exercise as well. Hypothetically, the significantly higher F4 and F5 after the cork and lip spreading exercise can be related to a possible shortening of the laryngeal cavity or laryngeal height [41]. Moreover, the higher $f_o$ values may have been induced by extra laryngeal height since this usually implies greater vocal fold tension. Future research should examine the specific anatomic correlates of F4 and F5, such as investigating the effects of retaining a high larynx during phonation on the formant frequencies. Comparing the results of the cork exercise with other research such as the study by Carew, Dacakis [46] is rather difficult, as this is the first study to investigate the effects of the cork exercise on the feminization of the voice in the transgender women population. Hancock and Helenius [52] and Gelfer and Tice [50] reported that F1 and F2 values moved toward average female values after targeting forward oral resonance. Considering their therapy protocol was different from the one in this study, the results are difficult to compare. However, the lack of significant F2 changes in every vowel during this study might be associated with a possible ceiling effect. The participants received pitch raising training prior to the articulation exercises, and although there was no specific focus on forward resonance, the F2 values might have already shifted as far forward as physiologically possible.

It should be mentioned that some increased formant frequencies have been found during this study, but our initial hypotheses were not confirmed. Additionally, the changes in formant frequencies were not found for every vowel. Although Carew, Dacakis [46] reported results that can be much more associated with our hypotheses such as increased F3 values due to the lip spreading exercises, their therapy program consisted of five therapy sessions with a duration of 45 minutes each. One exercise for one technique such as lip spreading and the cork exercise during this study might not be sufficient to detect substantial differences in these acoustic data. In contrast to Paltura and Yelken [83], the current study extracted the vowels from running speech, rather than performing acoustic analyses on isolated vowels. When extracting vowels from a phonetically balanced text that is being read aloud, they are more representative for actual daily communication.

To the best of our knowledge, this is the first study investigating vowel space while feminizing the voice of transgender women. In this study, the vowel space was calculated based on the first two formant frequencies of the vowels /a/, /i/ and /u/. It was hypothesized that vowel space would increase after the exercises. However, this was not the case. As shown on figure 4 and 5, the vowel space stays roughly the same and is smaller than the normative data [79] for cisgender women and cisgender men, even during the pre speech assessment. Despite the fact that it could be expected that the vowel space of transgender women is smaller than cisgender women, the difference with cisgender men is remarkable, i.e. the vowel space of the transgender women is considerably smaller than the average vowel space in cisgender men. It should be mentioned that the mental health conditions of the participants were not investigated in this study. To what extent personality factors and speech anxiety affects the size of the vowel space is subject for further research.

There is still need for further research concerning the correlation between an observed larger vowel space after articulation exercises and perceiving a voice as female or feminine. It is worth noting that both exercises only lasted 30 minutes each, which might not be enough to observe significant changes in vowel space. Future research should focus on a longer and more extensive therapy program.

All participants received pitch elevation training before participating in the study. During the articulation exercises, there was no focus on raising the $f_o$ of continuous speech. However, the articulation exercises caused a significantly higher $f_o$ after both exercises. In addition to the aforementioned hypothesis which included an increased laryngeal height, this result relates to the finding of a study by Carew, Dacakis [46]. They observed an increased $f_o$ as well, even though their participants did not receive any pitch elevation training before the start of their study. They reported this as a side effect of participants modeling the voice of a female clinician during intervention sessions. As a substantial amount of the therapy administered during tasks involved repetition of a clinician model, it is possible that these imitative tasks resulted in participants increasing their $f_o$ to more closely resemble that of the clinician. The authors of the study mention that for some transgender women, targeting an increase in pitch may not be necessary, because an increase of 30 Hz may occur incidentally while targeting other aspects of voice, such as oral resonance.

While comparing the outcome of both exercises, this study demonstrates that the lip spreading exercise has a higher impact on the F2 during vowel /a/ productions than the cork exercise. As previously demonstrated, F2 corresponds with a more forward tongue position. The finding in this study demonstrates that the lip spreading exercise might encourage this more advanced position of the tongue, more than the cork exercise does. Future research should include a study design comparing the impact of lip spreading exercises with forward tongue position exercises in this population.

The listening experiment in this study demonstrated a significant increase in female gender perception after both the lip spreading exercise and the cork exercise. Thus, the cisgender women and cisgender men who were blinded to the purpose of the study rated the randomized speech samples of the transgender women as sounding more feminine after each exercise. Listeners did not have any prior knowledge about speech pathologies and were not aware of the object of the study. Including cisgender speech samples and instructions to rate vocal quality and age were intended to be strategies to distract the listeners from the authors's primary interest in femininity ratings. Previous studies have included cisgender samples for their listening experiment as well [50, 84]. Gelfer and Tice [50] asked participants to rate the age and pleasantness to distract them from the investigator's main interest in gender identification and masculinity/femininity judgments. Hence, the authors safeguarded the naivety of their listeners through the process of their study. Carew, Dacakis [46] questioned the use of a naïve listener panels because of bad inter-rater reliability. Their listeners panel consisted of 12 fourth year speech pathology students, and suggested including experienced speech and language pathologists (SLPs) to rate speech samples during a listening experiment. The authors mentioned that rating a speech sample on a VAS, rather than using an equal-appearing-interval scale (EAI) with five to seven points, might have contributed to their poor inter-rater reliability, as it is an unfamiliar task for laypersons. According to Carew, Dacakis [46] future research should therefore include listeners who are experienced in the area of critically evaluating voice characteristics. Hancock, Colton [85], Houle and Levi [86] and Van Borsel, Van Eynde [87] did not report any problems regarding the inclusion of a VAS in their experiment. In this study, reliability analysis showed a good inter-rater reliability and listeners did not need further instructions when completing the listening experiment using the E-Prime software on the laptop. Consequently, the VAS in this study might have been a good medium to rate gender perception.

The significantly increased female gender perception observed through the listening experiment in this study does not correspond in a straightforward manner with the subtle changes in formant frequencies and vowel space. Aforementioned interpretations acknowledged the limited duration of the exercises to provide an explanation for the scarce differences in formant frequencies, but these do not justify the significant changes in the listening experiment. The significantly increased $f_o$ after the articulation exercises could possibly be an explanation for the increased female gender perception. However, correlation analyses showed that there is no relationship between these $f_o$ changes and the perceptual effects. Free and Dacakis [42] reported that clear speech might be related to a more feminine gender perception. Furthermore, previous research by Whitfield & Goberman (2017) showed that that clear speech was associated with a slower speech rate. During this study however, neither a significant slower speech rate was observed, neither a relationship was seen between speech rate and perceptual effects during the listening experiment. Additionally, as previously proven by Gallena, Stickels [33], a minimum increase of 20% of all formant frequencies results in a statistically significant increase of perceiving a voice as female or feminine. Even though not all of the formant frequencies increased significantly in this study, the listening experiment showed a significant increase in female gender perception. Concerning the formant analyses, it is worth noticing that during the process of extracting the vowels from the phonetically balanced text, the sound chain consisted of a limited amount of vowels. Maybe there were not enough vowels to perform reliable formant analyses. Future research should include sentences with enough /a/, /i/ and /u/ vowels to perform the acoustic analyses. Moreover, establishing a multiple regression equation using the acoustic parameters as predictors and the vocal gender rating as the criterion variable, might reveal the relative importance of each acoustic and articulatory aspect. Multiple regression allows us to determine how much of the variation in gender rating can be explained by these acoustic parameters "as a whole", but also the relative contribution of each variable.

This study presents some limitations which should be addressed in the future. Firstly, one exercise might not be enough to see important changes in the formant frequencies and consequently the vowel space. During this study, vowel space as well as F3 for the lip spreading exercise and F1-F2 for the cork exercise did not significantly increase, although this was hypothesized. Secondly, as some of our participants were above 60 years of age, it is possible that some of them experienced presbyphonia and that this confounded our findings [88]. Thirdly, as shown by several authors, it is important to measure the intra-rater reliability

[46, 50, 84]. Due to the fact that all of the speech samples were presented only once each, it was impossible to conduct these analyses. It is important not to overload the listeners with too many speech samples in order to preserve a high level of attention. However, by trying to accomplish this goal, intra-rater reliability was not conducted. Fourthly, there might have been an order effect of the two exercises. Although there was an interval period of at least one week, analyses demonstrated that the group starting with the lip spreading exercise had a larger impact of the lip spreading exercise on their F2 of vowel /a/, compared to the group starting with the cork exercise. Future research using another research design is needed to investigate this finding. For example, researchers could include a measurement in between both exercises, or include groups who receive exclusively one type of exercise. Furthermore, considering a randomized controlled trial as study design would be interesting to find out whether inclusion of a control group could result in similar findings.

## Conclusions

This study demonstrated that both lip spreading and cork exercises can increase formant frequencies of transgender women. Results showed that F2 /a/ and F5 /u/ significantly increased after the lip spreading exercise, as well as F3 /a/, F3 /u/ and F4 /a/ after the cork exercise. Furthermore, performing the lip spreading exercise has more impact on the F2 /a/ than the cork exercise. The vowel space stays the same after both exercises. These exercises achieve an indirect simultaneous increase of the $f_o$. The listening experiment suggests that the articulation exercises were associated with increased listener perceptions of femininity of the voice. Thus, cisgender listeners rated the speech of the transgender women more feminine after the therapy. Further research with a more extensive therapy program and listening experiment is needed to examine this preliminary evidence.

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