What Contributes to Masculine Perception of Voice Among Transmasculine People on Testosterone Therapy?

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Abstract: Voice is a highly salient and complex signal that people use to categorize another's gender. For transmasculine individuals seeking to align their gender expression with their gender identity, vocal presentation is a major concern. Voice-gender incongruence, where one's voice does not match their gender identity, can lead to vocal strain, fatigue, emotional distress, and increased risk of suicidality. Testosterone therapy, which uses exogenous testosterone to masculinize or androgynize the voice and other secondary sexual characteristics in individuals assigned female at birth, is one method to address this issue. However, many individuals remain dissatisfied with their voice post therapy, indicating that hormonal voice modification is a complex process not fully understood. In the present study, we use unmodified voice samples from 30 transmasculine individuals undergoing testosterone therapy and utilized multivariate analysis to determine the relative and combined effects of four acoustic parameters on two measures of gender perception. The results show that transmasculine individuals' speech is perceived as equally "masculine" as that of cisgender males, with both groups being statistically categorized as male at similar rates. Although mean fundamental frequency and formant-estimated vocal tract length together account for a significant portion of the variance in gender perceptions, a substantial amount of variance in gender perception remains unexplained. Understanding the acoustic and sociolinguistic factors that contribute to masculine voice presentation can lead to more informed and individualized care for transmasculine individuals experiencing voice-gender incongruence and considering testosterone therapy. For this population, addressing voice-gender incongruence has important implications for life satisfaction, quality of life, and self-esteem.

Key Words: Transmasculine speech—Fundamental frequency—Formant frequencies—Gender—Perception..

INTRODUCTION

Voice is one highly marked cue that people use to categorize another's gender.[1] For some transgender people seeking to align their gender expression with their gender identity or identities, concern around vocal gender presentation becomes especially salient. Voice is a concern reported by 79%-95% of transmasculine individuals,[2,3] and is rated lowest in satisfaction and with the highest desire for change among nine gendered traits.[4] Among the transgender population, having a voice that does not align with one's goals for expressing their gender identity, known as voice-gender incongruence, elevates the risk of vocal strain and fatigue[5,6] and emotional distress.[7-10] Among transgender men in particular, having a gender-congruent voice predicts greater well-being in the form of decreased anxiety and depression along with higher life satisfaction, quality of life, and self-esteem[11]—improvements that are especially important for this vulnerable population.[12]

Gender-affirming testosterone-based hormone therapy, hereafter referred to as testosterone therapy, is one approach to managing voice-gender incongruence in transmasculine individuals. "Transmasculine" encompasses a broad range of gender identities, including transgender men and non-binary individuals who lean toward a masculine presentation and/or gender. Testosterone therapy entails the use of exogenous testosterone administration to masculinize or androgynize the voice and other secondary sexual characteristics. In testosterone therapy, testosterone is regularly administered via intramuscular or subcutaneous injections, transdermally using gel or patches, or less commonly, via implanted pellets.[13] Testosterone is thought to alter the voice by causing several structural changes in the larynx, vocal folds, and vocal tract. In typical male cisgender pubertal development, the laryngeal cartilages and vocal folds lengthen and thicken.[14-18] As in cisgender males, these same structural changes are thought to cause the lowered fundamental frequency (f_o) and perceived pitch that accompany testosterone therapy in transgender men.[19] Research among transgender men undergoing testosterone therapy suggests that mean f_o changes substantially in the first 6 to 20 weeks of therapy,[6,19-22] and many studies focus primarily on mean f_o as a means of measuring the efficacy of testosterone therapy (eg,[23-25]). Testosterone is also thought to lengthen the vocal tract, which results in lowered formant frequencies in postpubertal cisgender men.[18] Preliminary

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research hints that testosterone may nudge vocal tract lengthening in transmasculine individuals as well[4,19]; however, more research is needed.

Differences in mean f_o and formants have been found to jointly influence the listener's perception of speaker gender among transgender and cisgender women,[26-28] but research is sparse regarding how formant frequencies affect perceived vocal gender of transmasculine speakers specifically. A notable exception is Groll et al,[29] who employed speech resynthesis to isolate the effects of specific acoustic characteristics (mean f_o, f_o contour, and formants) on the perception of gender in three transmasculine speakers sampled before and after initiation of testosterone therapy.

In the present study, we build on this work by using unmodified voice samples from 30 transmasculine individuals undergoing testosterone therapy and utilize multivariate analysis to determine the relative and combined effects of four acoustic parameters (mean f_o, f_o-SD, formant-estimated VTL, and cepstral peak prominence) on two measures of gender perception (ie, a continuous femininity-masculinity scale and male categorization frequency). Therefore, the first goal of this research is to quantify the amount of variance in vocal perception of gender explained by mean f_o and formant-estimated VTL, as well as to assess how much variance remains unexplained. Like Groll et al (2021), we expect that mean f_o will most impact gender perception, explaining a large majority of the variance in vocal perception of gender. A second goal is to compare raters' perception of gender for transmasculine voice samples with those of cisgender men and women to determine if the vowel segments of transmasculine people on testosterone therapy are, on average, perceived as masculine and identified as male-gendered based on their speech.

Although mean f_o and formant-estimated VTL have received the most attention, many other acoustic variables have been linked with gender perceptions (eg, Papeleu et al[30]; Leung et al, 2018[31]; Zimman, 2017[32]). Two of these, f_o variation (f_o-SD) and cepstral peak prominence (CPP), are investigated in the current study. One study showed that f_o variation was significantly lower in transgender men than cisgender women[4]; however, it is still unclear whether f_o variation explains any additional variation in perception of gender beyond its association with f_o. CPP is used primarily as an indicator of dysphonia severity and is particularly related to the perception of breathiness.[33] CPP may be relevant to gender-affirming voice care because breathiness is perceived to be a more feminine voice quality in both transgender and cisgender women (Gorham-Rowan and Morris[34]; Södersten et al[35]). Therefore, a third goal of this research is to explore if there is a significant difference in f_o variation and CPP between transmasculine speakers on testosterone and cisgender male speakers, and if these parameters explain significant variance in perception of gender. If so, it would suggest that these and other acoustic or sociolinguistic variables may be additional targets prioritized in gender-affirming voice care for transmasculine individuals.

METHODS

Participants

Vocal data were obtained from three participant groups: transmasculine people assigned female at birth, cisgender men, and cisgender women. For transmasculine participants, the present study used existing acoustic and physiological data from Hodges-Simeon et al[4] in which 30 transmasculine participants on testosterone therapy were recruited via Boston-area community health and LGBTQIA+ organizations. Participants ranged from age 18 to 50 (mean: 25.9 years ± 5.2) with no history of speech, language, hearing, or neurological disorders, and were speakers of General American English as a primary language. All were currently undergoing hormone replacement therapy with T for at least 9 months (M_{months} = 41.50, SD = 25.45). Four transmasculine participants self-identified as nonbinary and 26 participants self-identified as men. All were taking T for the purposes of masculinization. However, we did not ask participants about their ultimate goals, so we cannot determine where they aimed for their vocal presentation to fall on the continuums of masculinity and androgyny. Voice samples from 15 cisgender male and 15 cisgender female similar-aged participants were included for a total of 60 voice samples (cis-male age mean: 23.0 years ± 2.2; cis-female age mean: 22.6 years ± 2.8).

Voice analysis

Speakers were asked to use their normal speaking voice to produce the following vowels: /ɛ/ /i/ /ɒ/ /o͡ʊ/ /u/. Voice samples were collected in a quiet room using an Audio-Technica AT4041 Cardioid Condenser Microphone connected to a Focusrite Scarlett 2i2 audio interface. For formant-estimated VTL, estimates from Hodges-Simeon et al[4] were used. A summary of these procedures is provided here; however, see Hodges-Simeon et al[4] for more detail. Praat was employed to generate a wide-band spectrogram from the acoustic signal. Subsequently, the standard formant tracking software within Praat was used to compute the initial four formants. For each vowel, the automated formants were subjected to visual inspection, and the tracking software settings were adjusted until the formants matched the spectral representation of the signal. Formant values were derived from the stable central portion of each vowel. The third (F3) and fourth (F4) formant values for each participant were obtained by averaging the values from both vowels. These formant values were then used to compute estimates of VTL based on the following equation[36,37]:

$$\text{VTL} = \frac{(2n-1)\times c}{4\times f_n} \tag{1}$$

We used previous analyses of mean f_o and f_o variation (f_o-SD) from vowel sounds.[4] We also manually calculated mean f_o and f_o-SD from the Rainbow Passage in Praat version 6.1.40 by adjusting pitch range, voicing threshold, and cropping the remaining mistrackings such as those caused by vocal fry.[38] Regardless of which specific measures we used, the findings were nearly identical. Nevertheless, we report slightly updated numbers for mean f_o and f_o-SD in this paper. Second, f_o-SD was calculated in both Hz and semitones (ST). The Hz-to-ST conversion was calculated using the following formula based on f_o-SD values calculated in Hz.

$$\mathrm{ST} = (39.86) \times \log_{10}\frac{f_o}{\mathrm{reference}f_o}$$

The results in ST are used for the present analyses instead of Hz due to the logarithmic nature of ST reflecting the logarithmic perception of tones by humans.

Praat default settings were used to calculate CPP with the exception of the values "Time averaging window (s):" and "Quefrency averaging window (s)", which were set as 0.01 and 0.001, respectively.

Vocal perception of gender ratings

Vocal perception of gender ratings were collected from 157 listeners with no history of speech, language, hearing, or neurological disorders who were speakers of General American English as a primary language. Of these 157 participants, 81 self-identified as male, 74 as female, 1 as nonbinary, and 1 selected "prefer not to say". These participants were recruited via Amazon Mechanical Turk to complete a survey on voice and impression formation on Qualtrics. Participants were asked to use headphones for the duration of the study. After completing a sound check, raters were asked to listen to voices and rate them on a sliding visual-analog scale from "very feminine" (−100) to "very masculine" (+100), where "feminine" was described as "having qualities or an appearance traditionally associated with women," and "masculine" as "having qualities or appearance traditionally associated with men." Zero was designated as "neutral." Listeners rated all 60 voice samples. Ratings were averaged for each type of speech stimuli to estimate vocal perception of gender on a continuum (Cronbach's alpha = 0.86) where higher values are characterized as "more masculine." Listeners then categorized the gender of each voice sample given the discrete, categorical choices "Female," "Male," and "I don't know." Similar to Gelfer and Schofield,[39] we used two different metrics—the first rating vocal perception of gender via a continuum, and the second forcing a categorical binary choice to describe vocal perception of gender—to capture the nuance in gendering voice (ie, a voice categorized as "female" may still sound "more masculine"). Categorical responses from raters were then used to calculate a continuous variable—the percentage of raters who categorized each voice as male (referred to as "male categorization" below).

Analytic strategy

Our first goal was to compare mean vocal perception of gender and male categorization percentage between transmasculine, cisgender male, and cisgender female speakers. Because vocal perception of gender is expected to be bimodal clustering around cisgender male and female means, we used a nonparametric Kruskal-Wallis H test to assess mean differences. We also compared mean differences in CPP for each of the three groups using Analysis of variance (ANOVA). Second, using multiple regression analysis, we assessed the association between vocal perception of gender measures and acoustic measures. Zero-order correlations were conducted between vocal perception of gender and speech parameters (mean f_o, f_o-SD, formant-estimated VTL, and CPP). Two multiple linear regression analyses were conducted with vocal perception of gender ratings and the percent of raters choosing the male categorization as the dependent variables. f_o, f_o-SD, formant-estimated VTL, and CPP were simultaneously entered as predictors. The significance level was set at $\alpha = 0.05$. Multiple regression analysis allows us to determine which acoustic measures explain significant variance in vocal perception of gender, compare the amount of variance explained by each voice parameter (using R^2 as a measure of effect size), and how much variation in vocal perception of gender is left unexplained by our four voice characteristics.

RESULTS

How does vocal perception of gender of transmasculine speakers compare to vocal perception of gender of cisgender male and female speakers?

A Kruskal-Wallis test showed a significant effect of group on vocal perception of gender [$H(2) = 37.2$, $P < 0.001$] and male categorization [$H(2) = 36.0$, $P < 0.001$]. Pairwise comparisons (corrected using Bonferroni) showed that transmasculine speakers were significantly higher (ie, more masculine-sounding) than cisgender female speakers ($P < 0.001$), but slightly lower than cisgender male speakers ($P = 0.075$). The percent of individuals categorized as "male" was not significantly different between transmasculine and cisgender male speakers ($P = 0.16$), but both groups were significantly more likely to be categorized as male than cisgender females ($P < 0.001$). See Figure 1 for visual comparisons of the three groups and Table 1 for descriptive statistics.

Do CPP values differ between transmasculine and cisgender speakers?

A univariate ANOVA showed no significant effect of group for CPP [$F(2, 59) = 2.44$, $P = 0.10$].

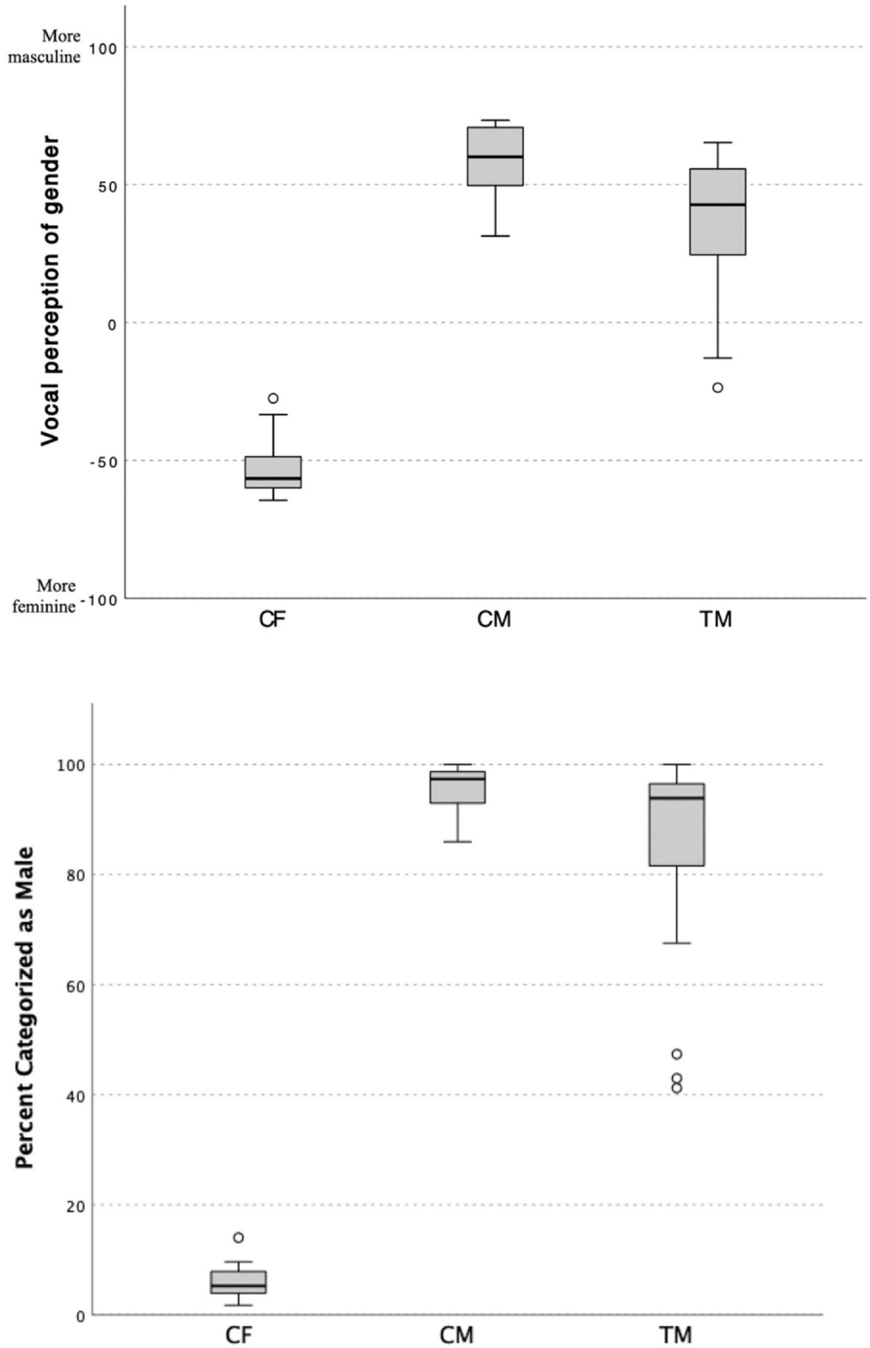

FIGURE 1. Comparison of cisgender female (CF), cisgender male (CM), and transmasculine (TM) speakers for vocal perception of gender and male categorization.

How much variance in vocal perception of gender and male categorization percentage is explained by mean f_o and formant-estimated VTL?

As a first step, correlations between vocal perception of gender, male categorization, and acoustic parameters were computed for the full sample. Perception of gender was significantly correlated bivariately with mean f_o, formant-estimated VTL, and f_o-SD, as well as CPP (Table 2).

To understand which of these speech parameters are most important to masculine gender perception, we conducted a simultaneous multiple regression predicting vocal perception of gender with mean f_o, formant-estimated VTL, f_o-SD, and CPP. The model explained 86% of the variance in perception of gender (R^2 = 0.86), with mean f_o being the most important predictor and formant-estimated VTL the second strongest predictor (Table 2). That is, in the full sample, mean f_o explained 675.6% of the variance in perception of gender (β = mean-0.81), whereas VTL explained only 3.6% of the variance (β = 0.19). f_o-SD and CPP did not contribute any additional variance to the model with mean f_o and formant-estimated VTL included. In other words, the significant bivariate correlations

TABLE 1.
Descriptive Statistics for Speech Characteristics: Mean (±SD) and Range

	Transmasculine	Cisgender male	Cisgender female
Vocal perception of gender	35.7–(±23.9)	54.5–(±23.2)	−49.5–(±18.6)
	−24-65	−15-73	−64-6
Percentage male categorization	83–(±20.7)	92.–(±16.7)	9-6 (±14.7)
	18-100	33-100	2-61
Mean f_o (Hz)	114.8–(±16.0)	112.3–(18.7)	191.2 (–26.5)
	92.9-144.3	91.2-154.4	135.2-232.1
f_o-SD (ST)	2.–(±0.5)	1.–(±0.2)	1.–(±0.6)
	1.2-3.4	1.4-1.9	0.9-3.8
Formant-estimated VTL (cm)	15-7 (±0.8)	16-6 (±0.6)	15-1 (±0.7)
	14-17	15-17	14-17
CPP	6.0 (±0.8)	6.1 (±0.9)	6.6-(±1.2)
	4.3-7.8	4.9-7.8	5.3-10.2

Notes: Vocal perception of gender scale ranges from −100 (feminine) to +100 (masculine). Mean f_o and f_o-SD were measured from the first sentence of the Rainbow Passage, numbers 1-10, and all vowels. Formant-estimated VTL was derived from the vowels /ɛ/ and /ɒ/.

between vocal perception of gender and f_o-SD and CPP were a product of their significant correlations with mean f_o (rs = −0.59 and 0.31, respectively). When mean f_o is included in the same model with f_o-SD and CPP, the latter two variables showed no significant association with perception of gender.

We also conducted the same model again, limiting the sample to transmasculine participants only. The results were similar to those of the full sample (Table 2, Model 2) in that mean f_o and formant-estimated VTL explained significant amounts of variation in perception of gender; however, the two variables only explained 44% of the variation overall. In this model, mean f_o explained 23% of the variance in perception of gender ($\beta = -.48$), whereas VTL explained 14.4% of the variance ($\beta = 0.38$).

We conducted parallel models predicting male categorization percentage for the entire sample and transmasculine participants only. The beta values and t statistics for these models were largely indistinguishable from the models predicting vocal perception of gender; therefore, only the latter results are presented in Table 2.

DISCUSSION

The primary goals of the present research were to 1) compare vocal perception of gender between transmasculine people, cisgender males, and cisgender females; and 2) to identify the acoustic parameters that contribute to vocal perception of gender. We assessed gender perceptions in two ways: a continuous scale ranging from feminine to masculine, and a forced-choice categorization (male, female, or don't know). These produced largely identical results, which showed that, to the naive listener, transmasculine individuals' speech is equally "masculine-sounding" as cisgender males and that the two groups are statistically categorized as male at equal rates. In addition, mean f_o and formant-estimated VTL together explained a substantial amount of variance in gender perceptions.

TABLE 2.
Multiple Regression Models Predicting Vocal Perception of Gender from Speech Parameters

	Unstandardized β (Std. Error)	Standardized β	R^2	t Statistic	Zero-order correlation
Model 1: Full sample (N = 58)					
f_o	−0.97 (0.09)	−0.81	0.66	−11.91***	−0.91***
Formant-estimated VTL	9.99 (3.52)	0.19	0.04	2.88**	0.63***
f_o-SD	−3.04 (4.97)	−0.03	0.00	−0.58	−0.04
CPP	−0.31 (2.64)	−0.01	0.00	−0.13	−0.27*
Model 2: Transmasculine only (N = 28)					
f_o	−0.73 (0.24)	−0.48	0.23	−3.00**	−0.59***
Formant-estimated VTL	11.13 (5.05)	0.38	0.14	2.21*	0.51**
f_o-SD	3.42 (7.26)	0.08	0.01	0.47	−0.17
CPP	−3.17 (4.44)	−0.11	0.01	−0.71	−0.02

Notes: *$P \leq 0.05$
**$P \leq 0.01$
***$P \leq 0.001$
†$P = 0.06$.
R^2 is included as a measure of effect size; when multiplied by 100, it gives the percent of variance explained by each predictor in the given model.

Using multiple regression, we examined the amount of variance in gender perception explained by each of four speech parameters (mean f_o, f_o-SD, formant-estimated VTL, and CPP). The results showed that mean f_o explained the largest proportion of variance, suggesting that listeners weigh mean f_o more heavily than other acoustic characteristics when making judgments of a speaker's femininity/masculinity and categorization of gender. This accords with previous research among transmasculine speakers,[29] cisgender speakers,[1] and transfeminine speakers,[39,40] showing that mean f_o has the largest effect on gender perception in all models.

The present research also showed that formant-estimated VTL explains a significant amount of variation in gender perception, albeit less than mean f_o. Interestingly, formant-estimated VTL explained a larger proportion of the variance in gender perception when the analyses were constrained to transmasculine speakers only (14%) versus the full sample (4%). This may be explained by previous research using this sample, which showed that 23% of the transmasculine participants' VTL fell outside of the cisgender male range and that the average transmasculine VTL was significantly shorter than that of cisgender males.[4] Several previous studies have also looked at the effects of formants on gender perception among transmasculine men (eg,[19,29]). This research adds to this work by attempting to quantify the amount of variance explained by formant-estimated VTL compared with mean f_o.

One of the goals of this research was to determine if acoustic parameters aside from mean f_o and formant-estimated VTL differ between transmasculine and cisgender male speakers and if these parameters contribute to perception of gender. Two other predictors (f_o-SD and CPP) did not explain any unique variance in masculinity perceptions; however, future studies will require larger sample sizes to more comprehensively investigate how these and other acoustic or sociolinguistic variables, such as individual formants,[29] timbre,[41] intonation,[42] intensity, oral resonance, f_o range variability, f_o contour,[29] or prosodic elements,[43] contribute to vocal perception of gender and therefore could be additional targets prioritized in gender-affirming voice training. Given that mean f_o and formant-estimated VTL together explained only 45% of the variation in perception of gender among transmasculine speakers (but 79% in cisgender males), additional studies may illuminate which other variables explain the remaining 55%.

Current methods of masculinizing the voice, with testosterone therapy being the most common,[2,9,44,45] are less empirically explored in comparison to feminizing voice care practices.[46] The high prevalence of vocal dissatisfaction even after testosterone therapy suggests hormonal voice modification is a complex multifactorial process that is not yet completely understood.[6,23,25,47] This indicates the need for further research to determine what factors beyond lowering mean f_o are implicated in the perception of a more masculine, feminine, or androgynous voice and gestalt gender presentation. Filling this gap in knowledge will allow more informed and individualized pathways of care for transmasculine individuals who 1) experience voice-gender incongruence and 2) are considering testosterone therapy, thus allowing them to achieve satisfaction with their voice through objective, evidence-based therapeutic goals. Identifying specific acoustic parameters associated with final voice satisfaction in transmasculine individuals can be used to determine earlier on in gender-affirming care if gender-affirming voice training may be of benefit in the future, and if so, what acoustic, pragmatic, and suprasegmental aspects of speech to prioritize based on their goals.

LIMITATIONS

One important limitation of the present research is the small sample size, which included only 30 transmasculine, assigned female at birth speakers. Therefore, our results may only apply to transmasculine, assigned female at birth individuals who wish to masculinize their voice to some degree. Additionally, our results may not generalize to all transmasculine individuals' gender expression targets nor to the broader array of gender-diverse individuals utilizing testosterone therapy. Future studies should aim to recruit a diverse group of transmasculine participants to capture the wide range of variation in vocal perception of gender goals in this population. A parallel goal would be to recruit a gender-diverse group of listeners as previous research has shown that listener characteristics may affect gender perception of voices (eg, Hancock et al[47]). An additional limitation of this research is that CPP is not paired with an additional measure to aid in its interpretation. CPP was chosen because of its previous association with gender and because of its value in assessing voice quality, for example, in a meta-analysis targeting 112 different measures of voice quality, Latoskek et al[48] found that CPP was the most promising measure of breathiness. Nevertheless, future studies should examine CPP in conjunction with measures such as harmonics-to-noise ratio and low-to-high ratio (L/H) when evaluating voice quality (ie, breathiness, roughness) as it relates to vocal perception of gender, which may reveal more significance of voice quality in vocal perception of gender that CPP alone cannot signal.

Future studies should include additional acoustic measures as this study does not present an exhaustive examination of all measures of gender-relevant acoustic parameters. The aim of the present study was to target the most gender-relevant elements of speech acoustics (mean f_o and formant-estimated VTL), adding two additional factors that may explain additional variation in gender perceptions, for example, those related to prosody[30,31,32]), nonverbal aspects of communication,[22] and language and syntactic choices related to social stereotypes about gender.[46]

Finally, future studies could also target more ecologically valid speech in everyday interactions. The isolation of vowels used in the present study provides scientific control that is especially valuable for the estimation of vocal tract length; however, information about other aspects of naturalistic speech is unavailable in these samples. Intonation, in particular, involves variations in pitch, rhythm, and emphasis that listeners link with femininity or masculinity. Research suggests that these speech patterns are particularly relevant for transgender and nonbinary speakers, supporting the use of intonation exercises in gender-affirming voice, speech, and communication training.[49]

Declaration of Competing Interest

None.

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