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DEPARTMENT OF ANTHROPOLOGY

HEARING WHAT YOU SEE: SEX DIFFERENCES AND CORRELATIONS BETWEEN HUMAN VOCAL, FACIAL, AND ANTHROPOMETRIC TRAITS

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ABSTRACT

Introduction: The relationship between vocal characteristics such as fundamental frequency and formant frequencies and anthropometric measurements of height and weight among others has been well studied over the years. Nonetheless, the literature is not consistent as to the significance and magnitude of their relationships. In addition, the relationship between vocal characteristics and other anthropometric measurements such as strength and objective facial measurements has yet to be investigated.

Method: The focus of this research is to contribute to the discussion on such relationships using new data from one of the largest samples to date (n=1014). Vocal traits and anthropometric measurements were collected as a part of the PSU ADAPT study. Voice traits were extracted from recordings using Praat. Objective facial measurements were obtained using principle component analysis on quasi-landmarks of 3d images of the face. These traits were analyzed for sex differences using Student's T test and for correlations using Pearson's product moment correlation.

Results: A number of statistically significant correlations are found between the vocal traits and anthropometric measurements. Characterizations of the formant frequencies (e.g., average formant frequency, formant dispersion, and formant position) show stronger correlations with the anthropometric characteristics than fundamental frequency in both males and females. Average formant frequency and formant position show more significant correlations with anthropometric traits relating to body size (e.g., height, weight, etc.) while formant dispersion shows more significant correlations with aspects of the face.

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Chapter 1

Introduction

Vocal characteristics

The voice is controlled by epithelial folds in the larynx in conjunction with supporting muscle tissue and organs of the respiratory system such as the mouth, lungs, and diaphragm. Together, these parts act as a vibratory system (Abitbol et al., 1999). The epithelial folds and vocal cords act as the vibratory body oscillator. The lungs and diaphragm act as the power source of the vibration, pushing the air throughout the system. The mouth, nasal passages, and the lips act as resonating chambers for the vibrations. This system produces vibrations, or sound waves, which possess a sinusoidal waveform (Humes and Bess, 2008). From this waveform many vocal characteristics or traits can be measured including the fundamental and formant frequencies.

One of the most well-known and well-studied vocal characteristics is the fundamental frequency (F_0). F_0 describes the lowest frequency of a resonating sound wave (Humes and Bess, 2008) and is quantified in terms of cycles per second or hertz (Hz). The F_0 measurement is most commonly associated with the pitch of an individual. A lower F_0 corresponds to a deeper-pitched voice while a higher F_0 measurement corresponds to a higher-pitched voice.

A person's F_0 is generally related to the thickness of his or her vocal cords which vibrate and the length of his or her vocal tract through which these vibrations resonate. Men tend to have thicker vocal cords than women due in part to the higher levels of testosterone which activate the androgen receptors in male laryngeal cartilage during puberty (Fitch, 1997; Humes and Bess, 2008). Additionally, during adolescence, men undergo a 30% greater increase in vocal tract length on average from their childhood state than women do (Jenkins, 2000). While the average F_0 values for males and females vary from study to study, the average F_0 value for adult males is between 110 and 120 Hz while average F_0 values for adult female is between 200 and 220 Hz (Fitch and Holbrook, 1970).

Formant frequencies, on the other hand, have traditionally offered valuable information about the vocal tract and voice patterns, especially in vowel production. The formant frequencies have been described as the resonant frequencies of the supralaryngeal vocal tract (González, 2004). These resonant frequencies correspond to various harmonics, or integer multiples, of the fundamental frequency.

In relation to vowel production, the change in location and amplitude of the formant frequencies provides information to a listener about which vowel is being spoken (Humes and Bess, 2008). In general, the formant frequencies decrease as the length of the vocal tract increases and as the lips round (Titze, 1994). Additionally, the individual formant frequencies may be increased and decreased with constrictions and manipulations of the mouth, pharynx, and jaw (Titze, 1994). Therefore, there might be a sex difference in formant frequencies due to differences in vocal tract length between males and females. Moreover, there is likely to be variation among individuals due to variation in facial shape in regions around the mouth, lips and jaw.

In a typical human voice, there are four formant frequencies: F_1, F_2, F_3, and F_4. Using these formants, three new vocal variables giving can be calculated to demonstrate the structure of the formants. These three variables are average formant frequency (F_n), formant dispersion (D_f), and formant position (P_f). Average formant frequency is simply the average of the various formants (Pisanski et al., 2014). Formant dispersion is the average distance between adjacent pairs of formants (Fitch, 1997). Formant position, on the other hand, is the average standardized formant value for the first *n* formants where formants are standardized using a z-score standardization (Puts et al., 2012). Formulae for F_N, $D_{f,}$ and P_f can be found in Appendix A.

Relationship with anthropometric measurements

The 1970s marked the start of a wealth of studies investigating the association of body size traits such as height and weight with vocal traits such as F_0. While some studies have investigated simple, objective correlations between an individual's F_0 and his or her height and weight (e.g., Lass and Brown 1978; Kunzel 1989; Graddol, David, Swann 1983), many of these studies focused on the identification of a speaker's height and weight based on a listener's perception of the speaker's voice (Lass et al 1979; Van Dommelen and Moxness 1995). A few studies addressed the potential effects that environmental factors such as age and smoking behavior may have on the vocal traits (e.g., Hollien, H. Shipp, 1972; Sorensen and Horii, 1982)).

The majority of these studies reported no significant correlations between F_0 and height and weight (Lass and Brown, 1978; Kunzel, 1989). Some more recent studies, on the other hand, have shown significant correlations between body size and formant measurements, D_F and P_F, (Puts et al., 2012). Interestingly, a recent meta-analysis has provided evidence which opposes the lack of correlations with F_0 and supports the correlations with D_f and P_f. This analysis combining data from over 15 studies found significant associations between F_0 and height in both males and females and between F_0 and weight in females in addition to significant associations between both D_F and P_F and height and weight in males and females (Pisanski et al., 2014). The magnitude of these correlations is modest at best which may suggest a small effect of height and weight on voice pitch.

Socio-cultural and evolutionary implications

Within the past 15 years many researchers have shifted their focus away from studying the relationship of voice and anthropometric measures and have begun to investigate the evolutionary and socio-cultural importance of the human voice. This research extends from some of the early hypotheses made by John Ohala which predicted that vocal frequencies acted as an amplification or accompaniment of signals conveyed by the body and face (Ohala, 1984). Among the new questions being addressed are how traits such as attractiveness and dominance might be perceived through the voice, how reproductive and/or mating success relates with vocal traits, and how hormone levels correlate with vocal traits. Additionally, this research has widened its scope of questions to include individual formant frequencies and the relationship between these frequencies (i.e., D_F, P_F, and F_N) as vocal traits in addition to F_0.

In particular, voice pitch and variation in voice pitch have also been linked with mating and reproductive success in several studies. In the Hadza hunter-gather population, males with a lower F_0 tended to have greater access to fertile females and produce more children (Apicella et al., 2007). In addition, in a study of college aged students, males with a more monotone voice, judged by the within-subject standard deviation of the F_0 (F_0-std), tended to have more sexual partners in the previous year (Hodges-Simeon et al., 2011). Moreover, a number of studies have demonstrated that F_0 has a significant negative correlation with testosterone in males, but not in females (Evans et al., 2008; Feinberg et al., 2008; Apicella and Feinberg, 2009; Puts et al., 2012). From these findings, it has been suggested that F_0 could act as a signal of hormonal qualities and/or immunocompetence, applicable to a female's mate choice (Evans et al., 2008; Apicella and Feinberg, 2009).

More data available on and more definitive conclusions about the relationships between the human voice and anthropometric characteristics of body size can only help further elucidate the socio-cultural and evolutionary reasons driving variation in vocal characteristics.

Facial Characteristics

Normal craniofacial variation is considered highly heritable. However, this heritability is not well understood from a biological perspective. Indeed, there are notable sex differences in many aspects of the human skull (Byers, 2011). In general, male skulls are larger with shaper features while female skulls are smaller with more gracile features. Specific aspects of the skull that vary between sexes include the browridge and the chin. Male skulls tend to have larger browridges while female skulls tend to have small or indistinguishable browridges. Male chins tend to be broad while female chins tend to be more pointed. While a suite of genes and hormones are suspected to influence sex differences and normal variation in the crania, little is known regarding which genes specifically drive this variation and the mechanisms through which these genes act.

In other species, such as some birds and dogs, the genetic basis of craniofacial variation has been more actively investigated. In Darwin's finch species (genus *Geospiza*), beak variation has been linked to mutations in the *Bmp* (bone morphogenetic protein) family of genes (Abzhanov et al., 2004). The importance of the *Bmp* gene family holds true in certain dog breeds as well. In these breeds, mutations in the *Bmp3* gene have been linked to variation in rostrum length and angle, palate and zygomatic arch width, and the depth of the neurocranium (Schoenebeck et al. 2012).

Until this point, most studies addressing human craniofacial variation have been focused on craniofacial dysmorphologies. For example, a mutation in the *Fgfr2c* gene has been linked to

Crouzon syndrome in which bones of the skull fuse prematurely (Martínez-Abadías et al., 2013). However, some research on normal craniofacial variation, that which does not result from pathology, has suggested that high levels of salivary testosterone may be correlated with perceived facial masculinity (Penton-Voak and Chen, 2004). In addition, a recent study using monozygotic and dizygotic twins suggests that the as much as 49% of the total variation in facial masculinity in both males and females may be due to additive genetic effects (Lee et al., 2013).

The genetic basis of facial variation in humans has been propelled further by recent genetic association studies. One such study identified five genetic influencing normal facial variation in Europeans (Liu et al., 2012) Another study proposed 20 autosomal genes as candidate genes affecting for variation in certain regions of the face, defined by spatially dense quasi-landmarks on 3d images (Claes et al., 2014). Among these genes were the protein coding genes *Slc35d1*, *Fgfr1*, and *Lrp6*. Using this type of methodology could expedite analyses of the relationship between regions of the face and the voice and/or other anthropometric measurements.

Project Aims

The aims of this project are to investigate the levels of sexual dimorphism in voice, body size, and the face and to reproduce the findings of previous studies of fundamental frequency and formant patterns in relation to anthropometric traits like height and weight. I predict that sexual dimorphism will be apparent in all traits and that both F_0 and formant measures (F_n, D_f, and P_f) will have significant correlations with anthropometric measures of body size. Additionally, I will seek to explore relationships between vocal characteristics and facial morphology. In this preliminary exploration, I expect that some vocal traits and facial aspects related to mouth and nose will have significant correlations.

In investigating the association between vocal and physical traits, a null hypothesis of no correlation between vocal and physical traits and an alternative hypothesis of a significant correlation between vocal and physical traits are being considered.

This represents the most extensive single study of its kind to date in terms of sample size and number of traits considered. In addition to contributing to the discussion on how vocal traits and anthropometric measures of body size are related, this project lays the foundation for future biological and morphometric studies to refine the potential relationships of objective measures of the voice and face. It also lays the foundation for future perception studies to further elucidate some of the potential sociological and evolutionary ramifications of the associations between vocal characteristics and anthropometric measurements of the face and body.

Chapter 2

Methods

Data Collection

The data for this project was collected as a part of the "Anthropometrics, DNA, and the Appearance, and Perceptions of Traits" (ADAPT) study led by Professor Mark Shriver at the Pennsylvania State University. Participants over the age of 18 in the ADAPT study were recruited from the University and the State College area and informed consent was obtained from each participant before sampling occurred (IRB approved study #44929). The data pertaining to the voice recordings, 3d facial images, height, sitting height, weight, hand strength, foot length age, and self-reported ancestry were used in this project.

Voice Recordings

Voice recordings were collected using a Roland (Los Angeles, CA) Edirol R-09HR recorder and a measurement microphone in a MONO input setting at an input level of 70 with high microphone gain. The recordings were taken in a booth equipped with soundproof foam in an isolated room of the laboratory (see Figure A1 for a picture of the set-up). The recording itself consisted of the date, the participant's sex and study ID number, the numbers 1 through 10, a list of elongated vowel sound words, and the first paragraph of Fairbanks' rainbow passage (Appendix B; Fairbanks, 1960). Specifically for the vowel sound section, participants were asked to elongate the vowel sounds in a series of short words for 2 to 3 seconds longer than normal to facilitate the measurement of formant points in the recording. The average duration of the recording was 1 min and 19 secs. The recordings were saved as a .WAV file denoting their sex (M/F) and their study ID number (i.e., M14XXXX) to facilitate the organization and analysis of the files.

Before reading the passage, participants were asked questions about their smoking history and behavior, their use of medications that could alter their voice pitch (e.g., testosterone supplements), and their current state of health (e.g., thyroid condition, cold, congestion, hoarse voice, etc.). Birth control was not included as a medication that could alter voice pitch as previous studies have shown no such associations (Reed Thompson, 1995; Abaza et al., 2007).

Participants who responded that they were a current smoker, taking medication that could alter their voice, or sick with a condition affecting the voice were not included in the final analyses in order to help attenuate some environmental factors which could alter their natural voice. For example, individuals who said they smoked cigarettes were excluded from the final analyses since previous studies have shown that people who smoke cigarettes tend to have lower than average F_0 measurements (Sorensen and Horii, 1982), potentially due to thickening of the surface epithelium (Ryan et al., 1955) and the basal cell layer (Auerbach et al., 1970) among other alterations. Unfortunately, the questions concerning smoking history and medication use were not asked in the first half of the sampling collection as these variables were not originally considered in the sampling process. Thus, some of the samples included in this analysis could be from participants currently smoking or taking medication

Additionally, some participants were excluded from the final analyses if they were not judged to be a native or proficient speaker of English. This was determined by answers to the pre-enrollment survey concerning the location in which the participant spent a majority of his or her life before the age of 18. If the answer to these questions were an English speaking country, the participant was included in the final analysis. If no answer was provided for these questions, a decision was made by listening to their recording and judging their proficiency. This was done as previous studies have shown that different languages use different vocal patterns (e.g., distribution and frequency of tonality, nasalization, voiced/unvoiced.; Ohala 1983).

Moreover, in order to minimize the environmental effects of age on the vocal and anthropometric traits, participants over the age of 40 were removed from this data set. In order to conduct a proper investigation of the effects of age on all these traits within this sample, a more evenly age-distributed sample would have been necessary.

In total, approximately 150 participants were excluded from the final results of the voice analyses to arrive at the final sample size of 1,014 (Table 7).

3D Facial Images

3d facial images were collected using the 3dMD (Atlanta, GA) Trio camera and the 3dMD acquisition program. Participants were asked to remove all earrings, glasses, and facial jewelry. Men were required to be clean-shaven and women were asked to refrain from using heavy make-up so as not to distort the 3d image. In addition, headbands and hair ties were used as necessary to pull back hair that covered any part of the face in order to expose the entire hairline. The participant was positioned so that his/her face was centered in all three of the camera windows. Images were immediately checked by the research staff to ensure images were not distorted. If distorted, another photo was taken. The composite images were exported from the 3dMD proprietary TSB format into a standard OBJ format for analyses.

Anthropometric Measurements

The standing height and sitting height of each participant was collected using a stadiometer. The weight of each participant was measured using a Tanita (Arlington Heights, IL) scale. For the standing height and weight measurements, participants were asked to remove their shoes and any heavy items (e.g., wallets, cell phones, watches) before measurements were taken.

Hand strength of both the left and right hand was measured using a JAMAR (Bolingbrook, IL) Hydraulic Hand Dynamometer. Participants were instructed to sit with their bicep against their side with their elbow flexed at a 90 degree angle and to squeeze the device three times as hard as they could. The highest reading of the three trials was recorded for each hand. The final hand strength measurement that was used was the average across the two hands.

Self-Reported Information

Self-reported demographic information (e.g., age, self-reported ancestry, handedness, birth city, etc.), and some anthropometric data (e.g., shoe size) were supplied by each participant through an online survey completed before their arrival to a sampling session. This information helped better categorize participants and ascertain some environmental factors that could influence the data.

Data Analysis

Voice Recordings

The voice files were edited as needed in Praat to remove loud background noises (e.g., bangs, cell phones, other people talking) and/or to fix speaking errors of the participants (e.g., the participant laughing, asking questions during the recording, reading the passage out of order). The goals of these edits were to remove any sounds not of the speaker that might have been analyzed by Praat for pitch and to keep the contents of the recordings consistent for all the participants. The files were then analyzed for F_0, F_0-std, and F_1-F_4 using automated scripts written in Praat's coding language (Appendix B). F_n, D_f, and P_f were then calculated from these measurements. Formulae for these measurements can be found in Appendix A.

Modifications were made to Praat's standard pitch settings (Boersma and Heuven, 2001) in order to compensate for a low thrumming noise on many of the recordings due to either laboratory machinery/equipment running in the adjacent room and/or the proximity of the microphone and the voice recorder. This low thrumming noise seemed to cause Praat to misidentify periods in the sound waves (i.e., double counting cycles which produces a F_0 twice that of the normal range), to determine pitch for unvoiced fricatives and other aperiodic sounds (i.e, for "f" sound in the word five, "th" sound in the word three, and "s" sound in the word looks), and to allow unnatural octave-jumps. In some cases, for example, Praat reported F_0 values in the 400 Hz and 500 Hz range which are outside the normal speaking range of F_0 values for adult humans. The modifications were chosen on a trial and error basis (Tables 1 and 2).

Table 1: Pitch setting manipulations for male-specific automated Praat scripts

Pitch Setting	**Male**		
	1	**2**	**3**
AC/CC	CC	CC	CC
Pitch Floor	75	75	75
Pitch Ceiling	300	200	300
Voicing Threshold	0.45	0.45	0.6
Octave Jump-Cost	0.35	0.9	0.7
Voiced/Unvoiced Threshold	0.14	0.14	0.3

Table 2: Pitch setting manipulations for female-specific automated Praat scripts

Pitch Setting	Female						
	1	2	3	4	5	6	7
AC/CC	CC	CC	CC	AC	CC	AC	CC
Pitch Floor	100	100	100	150	150	150	150
Pitch Ceiling	500	350	500	400	400	400	350
Voicing Threshold	0.45	0.45	0.6	0.6	0.6	0.45	0.6
Octave Jump-Cost	0.35	0.9	0.7	0.7	0.7	0.35	0.7
Voiced/Unvoiced Threshold	0.14	0.14	0.3	0.3	0.3	0.14	0.3

In order to determine which modifications most accurately measured F_0, the script outputs for mean F_0 were compared to gold standard F_0 outputs. The gold standard was established by counting cycles of waveforms by visual inspection in Praat's editor window and then multiplying the number of cycles by the inverse of the time duration of the chosen segment of the recording. Nine male recordings and fifteen female recordings were randomly chosen in an attempt to encompass the entirety of F_0 distribution. For male recordings ten cycles and for females recordings, twenty cycles within the word "sunshine" were counted and used to determine the gold standard F_0 (data not shown). While the first gold standard attempt successfully eliminated certain analysis settings, several of the analysis settings resulted in recordings with F0 measurements which showed equally high correlations with the gold standard F_0 (Tables 3 and 4).

Table 3: Correlation of 10 cycle gold standard F0 measurements with automated Praat script F0 measurements for males using Pearson's product moment correlation coefficient (r) values

Male Analysis Setting	r	p
1	0.9941	<0.0001
2	0.9941	<0.0001
3	0.9941	<0.0001
4	0.74503	0.0213

Table 4: Correlation of 20 cycle gold standard F0 measurements with automated Praat script F0 measurements for females using Pearson's product moment correlation coefficient (r) values

Female Analysis Setting	r	p
1	0.24145	0.3505
2	0.55381	0.0260
3	0.55262	0.0326
4	0.99843	<0.0001
5	0.99880	<0.0001
6	0.74617	0.0009
7	0.99880	<0.0001

Therefore, to further determine which measurement was most accurate, a second gold standard was created using the average of seventeen measurements at various points in the recordings. These measurements were taken from sounds of six vowels, and eleven words from the recordings in order to sample a diverse selection of sounds spoken by the participant. The average of these seventeen F_0 measurements was then compared to the mean F_0 measurements of the automated Praat script averaged across the entirety of the recording (data not shown). Only the three most highly correlated scripts were used in this second analysis. A difference between the scripts was noted this time (Tables 5 and 6). The 3rd male setting and the 7th female setting both had the highest correlation for their respective datasets and were used to analyze the entire dataset as a result.

Table 5: Correlation of average gold standard F0 measurements with average automated Praat script F0 measurements for males using Pearson's product moment correlation coefficient (r) values

Male Analysis Setting	r	p
1	0.99391	<0.0001
2	0.98541	<0.0001
3	0.99589	<0.0001

Table 6: Correlation of average gold standard F0 measurements with average automated Praat script F0 measurements for females using Pearson's product moment correlation coefficient (r) values

Female Analysis Setting	r	p
4	0.85175	0.0036
5	0.88750	0.0014
7	0.98669	<0.0001

3D Facial Images

The 3d facial images were scan-cleaned in 3dMD Patient software in order to remove extraneous parts of the image, such as the hair, ears, and any abnormalities created by the camera, and to reposition the face for analyses (Figure A2). The placement of 7000+ landmarks and quasilandmarks in a mesh and the subsequent modeling of the 3D facial images scores were performed as described in by Claes *et al.* (2014). Principle component analysis (PCA), a data reduction technique to consolidate interrelated variables was performed in R-Studio (v. 3.1.1) statistical software. More information regarding PCA may be found in Jolliffe, 2002.

In order to visualize the effects of the PCs, heat maps of seven PCs, two of which had significant correlations with F_0 in both sexes, two of which had significant correlations with D_f in both sexes, and three of which had correlations passing a Bonferroni corrected significance level, were generated in the MATLAB software. Three different heat maps per PC (Figures 2-7) were generated to show the effect of the PCs on face shape change parameters (FSCP) such as normal displacement, curvature difference, and area difference in the face as done in Claes *et al.* (2014). The effects shown in these heat maps apply to both males and females.

For the heat maps of normal displacement, points shaded in red indicate that they are moving outwards from the plane that is tangential to the surface at that point from the negative to positive end values of the PC axis. Points shaded in yellow follow the same trend as the points in red except at a lower magnitude. The points shaded in blue indicate that the face is moving inward to the plane tangentially at that point from negative to positive end of the PC axis. The areas shaded in green, however, show no significant difference between values of the PCs. For the curvature difference, the points in red are more convex while the points in blue are more concave from the negative to positive end of the PC axis. For the area difference, the points in red show an increase in surface area while the points in blue show a decrease in the surface area. Transformations of a consensus face representing the extreme ends of each PC axis are provided in order to help demonstrate the effects of the PCs (Figures A4-A7)

Anthropometric Measurements

Standing height, sitting height, weight, and hand strength measurements were all entered into a Microsoft Excel spreadsheet. Foot length (cm) was calculated from the self-reported shoe size by using a shoe size conversion guide (Figure A5). All shoe sizes were assumed to be American sizes unless otherwise noted.

Statistical Analyses

The majority of the statistical analyses were conducted using SAS (v. 9.4). Correlations were conducted between the vocal characteristics and anthropometric measurements using Pearson's product moment correlation coefficient (r) and a pairwise deletion method. Student's t-test for difference of means for independent samples was performed for each of the vocal and anthropometric traits.

Due to the number of comparisons being made, a Bonferroni correction for multiple comparisons was implemented to further determine the significance of the correlations and means differences. The total number of tests used was 116, encompassing all vocal trait, anthropometric trait, and face PCs. The Bonferroni adjusted α value was calculated by dividing the tradition α level (0.05) by the number of tests (n = 116), resulting in an $\alpha_{crit} = 0.0004$.

In total, there were 1,014 subjects in the sample. See Table 7 for a demographic breakdown of the sample. For some of the statistical tests, there were fewer than the total number of subjects as participants were given the option to refrain from giving certain measurements, some of the anthropometric measurements were not collected at every sampling session, and some of the measurements were incorrectly taken.

Table 7: Sample summary statistics of participants included in this study

Demographic Information	
Sex	
Males (n, %)	372 (36.69%)
Females (n, %)	642 (63.31%)
Age	
Mean (Std)	
Males	21.17 (3.31)
Females	20.75 (3.04)
Range	18-40
Self-Reported Ancestry	
European	714
African American	134
Other…	156
Unknown	10

Chapter 3

Results

Trait Averages

Averages and standard deviations for each of the traits measured can be found in Tables A1 and A2. The mean F_0 value for males is 109.71 Hz (standard deviation: 13.89 range: [79.88, 163.31]) while the female mean F_0 value is 199.07 Hz (standard deviation: 18.97; range: [158.44, 271.19]). These mean F_0 measurements are slightly lower than the averages presented in the introduction (reported by other research groups) but not outside the range of previously reported F_0 values compiled in Pisanski et al. (2014). Overall, the data further demonstrates that F_0 is a sexually dimorphic trait ($t = 79.47$, $p < 0.0001$, Cohen's $d = 5.39$) with very little overlap. The distribution of F_0 values is presented below in Figure 1.

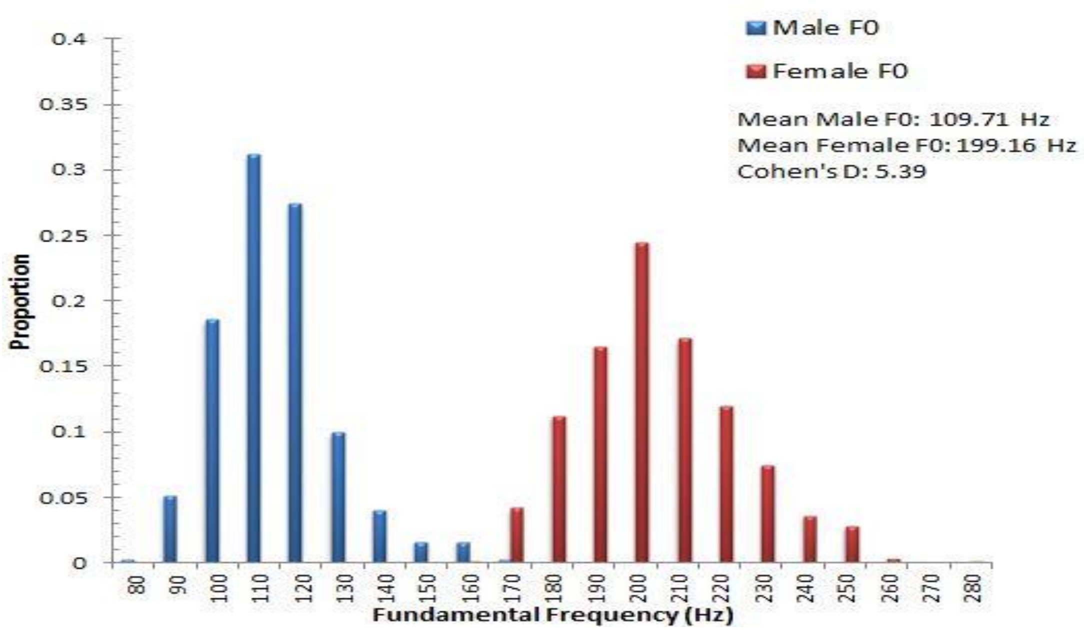

Figure 1: Histogram of male and female F0 values

While F_0 is the most sexually dimorphic of all the vocal characteristics examined, many of the other characteristics are also sexually dimorphic (see Table A1). The only trait which does not appear sexually dimorphic is P_F ($t = -0.04$, $p = 0.97$, Cohen's $d = 0.0024$). For all other vocal traits, the intersex means differences are significant with a large effect size ($p < 0.0001$ for all, Cohen's d: [1.73-4.25]).

All of the anthropometric traits investigated are also sexually dimorphic with the exception of BMI ($t = -0.65$, $p = 0.52$, Cohen's $d = 0.04$). Weight, although having a statistically significant t-value ($t = -11.63$, $p < 0.0001$), has one of the lowest effect sizes of all the traits (Cohen's $d = 0.76$). For all other anthropometric traits, the intersex means differences are significant and effect sizes are large ($p < 0.0001$, Cohen's d: [1.56-2.26]; see Table A2).

After performing a Bonferroni correction for multiple comparisons ($n = 116$), all traits which were previously statistically significant at $\alpha = 0.05$, remain significant at the new Bonferroni adjusted α-level, 0.0004.

Many of the face PCs also exhibited significant level of sexual dimorphism (Table A3). 50 of the 100 PCs have statistically significant mean differences at the 0.05 significance level, (Cohen's d: [0.13-1.13]). After a Bonferroni correction ($\alpha = 0.0004$), the means remain statistically different from zero in only 26 of the 100 PCs, a reduction in 24 PCs. Cohen's d values for these 26 PCs range from 0.24 to 1.13.

Overall, mean Cohen's d values for voice traits, anthropometric measures of body size, and face PCs were significantly different from each other based on a Tukey mean comparison at $\alpha = 0.05$.

Table 8: Average Cohen's d value for the traits significant at the α= 0.05 level

Trait Set	Average Cohen's d
Vocal[1]	3.10
Body Size Anthropometric[2]	1.93
Face PCs	0.29

1 excludes P_f
2 excludes BMI
3 see table A3 for the list of 50 PCs which pass the significance cut-off

Correlations between vocal traits and body size traits

A number of significant correlations are found between vocal traits and body size traits (see Tables A3-A6 for a full list of correlations). In particular, F_0 has a significant correlation with height ($r = -0.14$, $p < 0.01$) but the correlation with sitting height just missed the cutoff for significance ($r = -0.10$, $p = 0.0505$) in males. In females, F_0 has a significant correlation with height ($r = -0.14.$, $p < 0.001$) and weight ($r = -0.09$, $p < 0.05$). F_0-Std only has a significant correlation with hand strength in males ($r = -0.12$, $p < 0.05$).

The majority individual formants, F_1-F_4, have significant correlations with the individual traits (see Tables A4-A7). The correlations of the variables combining all of these formants are analyzed here more closely. D_f has a significant correlation with height ($r = -0.15$, $p < 0.01$), weight ($r = -0.16$, $p <0.01$), and sitting height ($r = -0.15$, $p <0.05$) in males and weight ($r = -0.20$, $p < 0.0001$) in females. F_n and P_f have significant correlations of similar magnitudes with all of the anthropometric traits in both males and females, many of which had the highest magnitudes than any other correlation. For example, in males the correlation magnitudes between F_n and P_f and height (F_n: $r = -0.27$, $p <0.0001$; P_f: -0.29, $p <0.0001$) are about double the correlation magnitude between F_0 and height ($r = -0.14$, $p < 0.01$). In females, the correlation magnitudes between F_n and P_f and weight (F_n: $r = -0.31$, $p < 0.0001$; P_f: $r = -0.32$, $p < 0.0001$) are more than triple the correlation magnitude between F_0 and weight ($r = -0.09$, $p < 0.05$). Overall, the correlations with the highest magnitude are between F_n and P_f and foot length in males (F_n: $r = -0.29$, $p < 0.0001$; P_f: $r = -0.30$, $p < 0.0001$) and between F_n and P_f and weight in females (F_n: $r = -0.31$, $p < 0.0001$; P_f: $r = -0.32$, $p < 0.0001$).

Overall, these new findings do not replicate the results of many previous studies (Lass and Brown 1978; Graddol, David, Swann 1983; Kunzel 1989). They do, however, support the relationships determined by Pisanski *et al.*'s recent meta-analysis (2014). The only major difference between the two is that this data-set shows a significant correlation between F_0 and height in females while the meta-analysis did not. The rest of the correlations are similar both in terms of magnitude and direction (Tables 9 and 10).

Table 9: Comparison of height vs. vocal trait correlations between the ADAPT study and the Pisanski *et al.* meta-analysis

Height vs.	ADAPT Study				Pisanski et al. (2014)			
	Male		Female		Male		Female	
	r	p-value	r	p-value	$\bar{r}$	p-value	$\bar{r}$	p-value
F_0 (Hz)	-0.14	0.01	-0.15	<0.01	-0.14	0.01	-0.07	0.06
F_1 (Hz)	-0.11	0.03	-0.14	<0.01	-0.13	0.01	-0.04	0.29
F_2 (Hz)	-0.23	<0.0001	-0.01	0.71	-0.22	<0.001	-0.19	<0.001
F_3 (Hz)	-0.19	<0.01	-0.07	0.09	-0.26	<0.001	-0.22	<0.001
F_4 (Hz)	-0.20	<0.0001	-0.04	0.31	-0.30	<0.001	-0.25	<0.001
F_n (Hz)	-0.27	<0.0001	-0.07	0.09	-0.31	<0.001	-0.22	<0.001
D_f (Hz)	-0.15	<0.01	-0.03	0.52	-0.18	<0.001	-0.24	<0.001
P_f (Hz)	-0.29	<0.0001	-0.18	<0.0001	-0.29	<0.001	-0.21	<0.001

Table 10: Comparison of weight vs. vocal trait correlations between the ADAPT study and the Pisanski *et al.* meta-analysis

Weight vs.	ADAPT Study				Pisanski et al. 2014			
	Male		Female		Male		Female	
	r	p-value	r	p-value	$\bar{r}$	p-value	$\bar{r}$	p-value
F_0 (Hz)	-0.03	0.62	-0.09	0.02	-0.03	0.3	-0.14	<0.001
F_1 (Hz)	-0.13	0.01	-0.16	<0.0001	-0.15	0.01	-0.08	0.06
F_2 (Hz)	-0.13	0.01	-0.13	<0.01	-0.09	0.12	-0.22	<0.001
F_3 (Hz)	-0.11	0.04	-0.10	0.01	-0.18	<0.01	-0.16	<0.001
F_4 (Hz)	-0.22	<0.0001	-0.19	<0.0001	-0.15	0.01	-0.24	<0.001
F_n (Hz)	-0.23	<0.0001	-0.18	<0.0001	-0.22	<0.001	-0.23	<0.001
D_f (Hz)	-0.16	<0.01	-0.20	<0.0001	-0.10	0.02	-0.21	<0.001
P_f (Hz)	-0.23	<0.0001	-0.32	<0.0001	-0.25	<0.001	-0.22	<0.001

Correlations between vocal traits and aspects of fascial shape

Additionally, a number of significant correlations are found between the vocal traits and the 100 face PCs (see Tables 12 and 13 for a short list of significant correlations; Tables A8 and A9 for a full list of significant correlations). The magnitude of these correlations ranges from 0.10 to 0.20 in males and from 0.08 to 0.18 in females. The direction of the correlation varies from comparison to comparison. Overall D_f shows the most significant correlations with the face PCs in both males (n = 18 with $p < 0.05$) and females (n = 28 with $p < 0.05$). F_0 shows the fewest significant correlations in both males (3 with $p < 0.05$) while F_0-std shows the fewest in females (n = 11 with $p < 0.05$). However, F_0 did show the highest average correlation magnitude with the face PCs in males ($\bar{r}$ = 0.157, st. dev. 0.045) while F_n shows the highest average correlation magnitude in females ($\bar{r}$ = 0.123, st. dev. = 0.0293) with P_f close as well ($\bar{r}$ = 0.121, st. dev = 0.0297). See Table 11 for a complete table of average r values.

Table 11: Average r value for the correlations between the PCs and vocal traits in both males and females

Sex	F_0		F_0-Std		F_n		D_f		P_f	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Males	0.157	0.045	0.126	0.0131	0.124	0.0143	0.130	0.0263	0.120	0.009
Females	0.106	0.021	0.093	0.0127	0.123	0.0293	0.115	0.0246	0.121	0.0297

In both males and females, PCs 4 and 11 are both significantly correlated with F_0 (males: PC 4-F_0 $r = -0.16$, $p < 0.01$, PC11-F_0 $r = 0.20$, $p < 0.001$; females: PC4-F_0 $r = -0.12$, $p < 0.01$; PC11-F_0 $r = 0.13$, $p < 0.001$). PCs 75 and 91 are both significantly correlated with tonicity in both sexes (males: PC 75-F_0-stdev $r = -0.11$, $p < 0.05$, PC 91-F_0-Std $r = -0.14$, $p < 0.01$; females: PC 75-F_0-Std $r = -0.09$, $p < 0.05$, PC 91-F_0-Std $r = 0.09$, $p < 0.05$).

While no PCs are significantly correlated with F_n in both sexes, three PCs (PCs 8, 10, and 59) are significantly correlated with D_f and one PC (PC 28) is significantly correlated with P_f (males: PC 8-D_f $r = -0.14$, $p < 0.01$, PC 10-D_f $r = -0.14$, $p < 0.01$, PC 59-D_f $r = 0.14$, $p < 0.01$, PC 28-P_f $r = -0.13$, $p < 0.05$; females: PC 8-D_f $r = -0.1$, $p < 0.01$, PC 10-D_f $r = 0.15$, $p < 0.001$, PC 59-D_f $r = -0.11$, $p < 0.01$, PC 28-P_f $r = -0.11$, $p < 0.01$).

Table 12: Select significant correlation between PCs and F_0 and F_0-std in both sexes

	F_0				F_0-Std			
	Males		Females		Males		Females	
	r	p	r	p	R	P	r	p
PC4	-0.16	<0.01	-0.12	<0.01	-0.12	<0.05		
PC11	0.20	<0.001	0.13	<0.0001				
PC75					-0.11	<0.05	-0.09	<0.05
PC91					-0.14	<0.01	0.09	<0.05

Table 13: Select significant correlation between PCs and F_n, D_f, and P_f in both sexes

	F_n				D_f				P_f			
	Males		**Females**		**Males**		**Females**		**Males**		**Females**	
	R	**p**	**r**	**p**	**r**	**p**	**r**	**P**	**r**	**p**	**r**	**p**
PC 8			-0.13	<0.001	0.14	<0.01	-0.10	<0.01			-0.13	<0.01
PC 10	-0.11	<0.05			-0.14	<0.01	0.15	<0.001				
PC 28			-0.13	<0.01			-0.15	<0.001	-0.13	<0.05	-0.11	<0.01
PC 30					-0.22	<0.0001						
PC 31			0.18	<0.0001			0.14	<0.001			0.17	<0.0001
PC 32							0.19	<0.0001				
PC 59					0.14	<0.01	-0.11	<0.01				

Using heat maps to take a closer look at which aspects of the face correlate with certain vocal traits, it becomes clear that many of the PCs deal with aspects of the face involving the lips, the chin, the philtrum (depression in middle area between upper lip and nose), the nares (nostrils) and nasal bridge, and the maxilla. While these PCs also deal with regions of the face such as the orbits and forehead, the magnitude of the FSCPs in these regions will not be examined here as these regions of the face are most likely not associated with the vibratory system of voice production described in the introduction.

Looking at the heat map of PC 4 (Figure 2), for example, it is possible to see that PC 4, which has a significant negative correlation with F_0 in both males and females, affects areas around the lips, chin, and nasal bridge with regards to displacement. These colored regions of the heat map show that the chin and lower lips come out from the plane while the nasal bridge, nares, and parts of the maxillary region go in towards the plane. There are also slight curvature differences in which the philtrum is more concave. Moreover, strong area differences are visible in the philtrum and lips suggesting a larger surface area in these regions.

The negative correlation between PC 4 and F_0 suggests that individuals with a greater F_0 have more outward projecting chins and more inward projecting nasal bridges in addition to a greater surface area in the area of the lips, chin, and philtrum. Individuals with a lower F_0 would have the opposite - more inward projecting chins, more outward projecting nasal bridges in addition to reduced surface area in the lips, chin and philtrum.

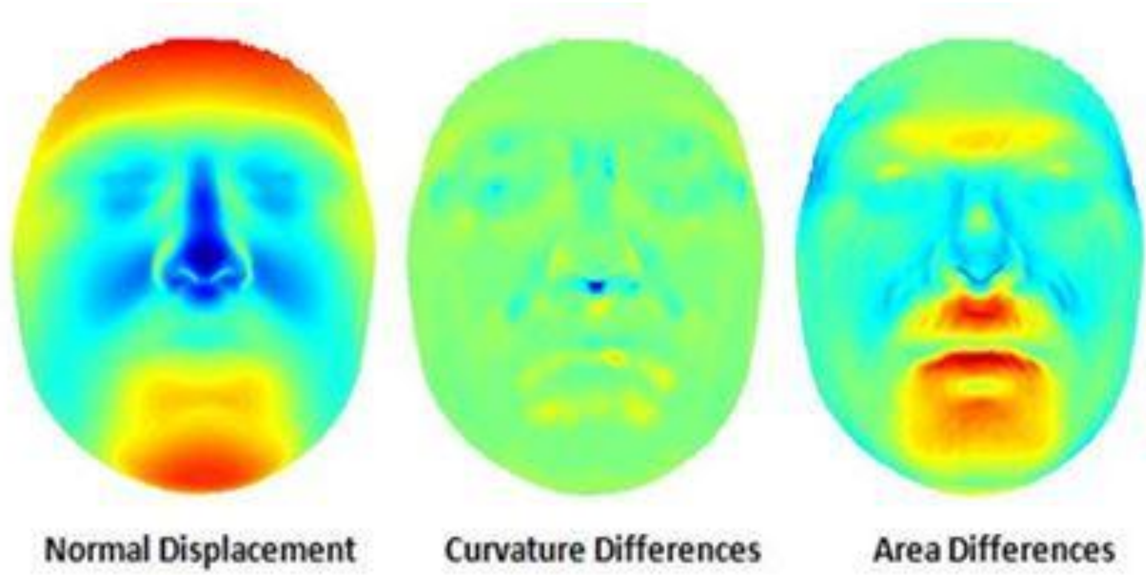

Figure 2: Heat maps for PC 4.

Additionally, PC 11 (Figure 3), which has a significant positive correlation in both males and females, also shows an inward displacement of the nares and lips, and an outward displacement of the chin, to an extent. There is also a large effect upon curvature showing higher convexity in the philtrum. In addition, there are very large area differences in the chin and maxillary regions suggesting larger surface area in these regions as well as smaller area differences in the nares and philtrum suggesting less surface area in these regions.

The positive correlation between PC 11 and F_0 suggests a similar trend in that individuals with a greater F_0 would have an inward projecting nasal bridge and outward projecting nares in addition to an increase surface area in the philtrum and nares and a decrease in surface area in the maxillary region. Individuals with a lower F_0 would have more inward projecting nares and lips in addition to an increase surface are in the maxillary region and chin and a decrease in surface area of the nares and philtrum.

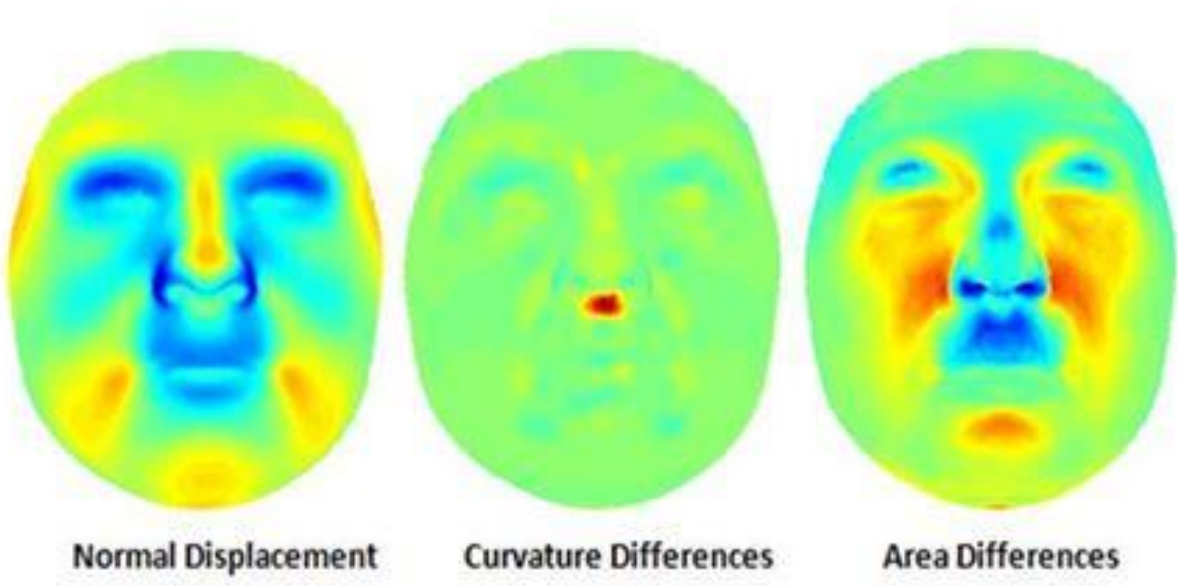

Figure 3: Heat maps for PC 11

PC 8 (Figure 4), which has a significant negative correlation with D_f has slight signals in displacement with the maxilla, nasal bridge, and chin. These signals suggest an outward displacement from the plane in these areas and a slight inward displacement from the plane in the lips. In curvature differences, the philtrum appears to be more convex while the lateral edges of the lips appear more concave. There are more notable differences in area, however, in the lips, maxilla, and nasal bridge in area displacement suggesting an increase in surface area in these aspects.

The negative correlation here suggests that individuals with greater D_f have a more outward projecting nose, maxillary region, and chin, in addition to an increase in surface area in the nasal bridge, maxillary region, and lips.

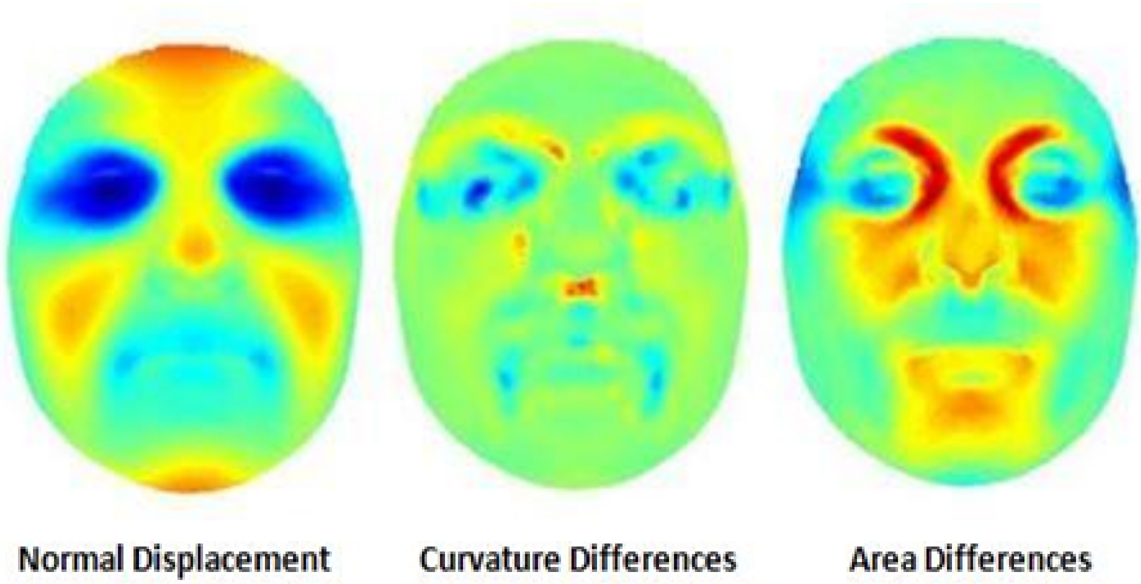

Figure 4: Heat maps for PC 8

PC 10 (Figure 5), which has a positive correlation with D_f in females but a negative correlation in males has strong signals of outward displacement around the chin, upper lip, and mandibular region and of inward displacement in the lower lip. There are also weaker signals of outward displacement in the tip of the nose and inward displacement just above the upper lip. Additionally, there are some curvature differences with the lips and philtrum being more convex. Area differences suggest less surface area in the lips but greater surface area in the chin and tip of the nose.

The difference in direction of the correlations seen in males and females between these traits suggest that they will see opposite patterns. Males with greater D_f have more outward projecting noses, chins, and jaws with an increase in surface area in the nose and chin and a decrease in surface area in the lips and philtrum. Females show the opposite pattern.

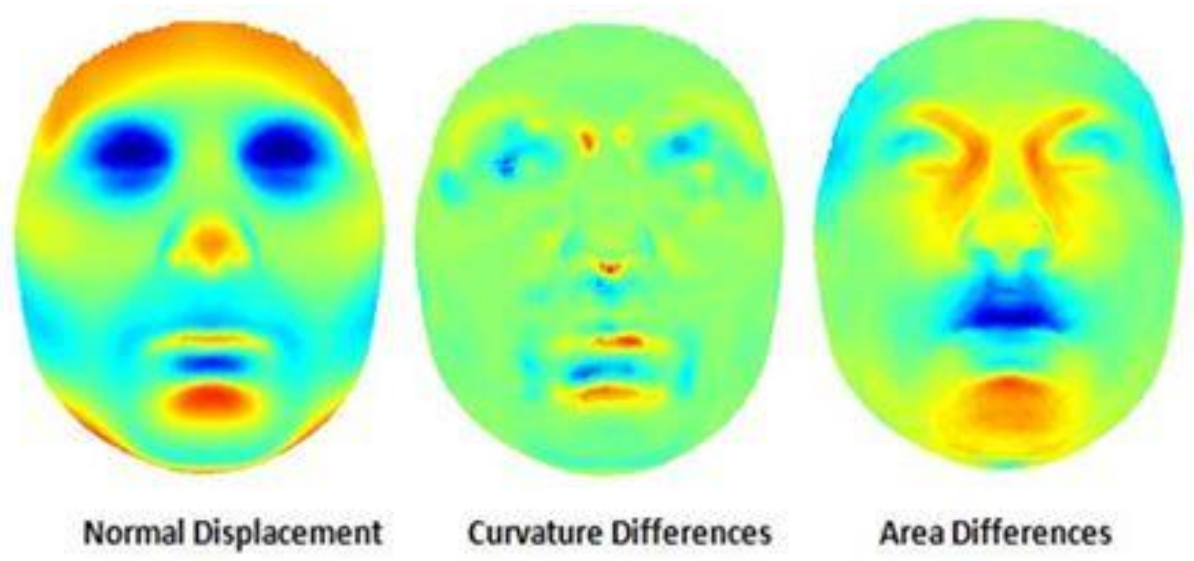

Figure 5: Heat maps for PC 10

After Bonferroni correction for multiple comparisons ($\alpha = 0.0004$), only a few of these correlations remained significant. These correlations were between D_f and PC 30 in males and between F_n and P_f and PC 31and D_f and PC 32 in females.

In males, PC 30 (Figure 6), which has a negative correlation with D_f, has strong signals of inward displacement in the lips and nares in addition outward displacement in the nasal bridge and parts of the jaw. A strong curvature difference suggesting convexity in the philtrum is also apparent. Little area difference is seen in the face with this PC except for small increases in surface area around the lips and larger decrease in surface area in a small portion of the chin.

The negative correlation between these traits suggests that males with greater D_f would have a more outward projecting nose and chin and more inward projecting lips as similarly suggested by PCs 8 and 10.

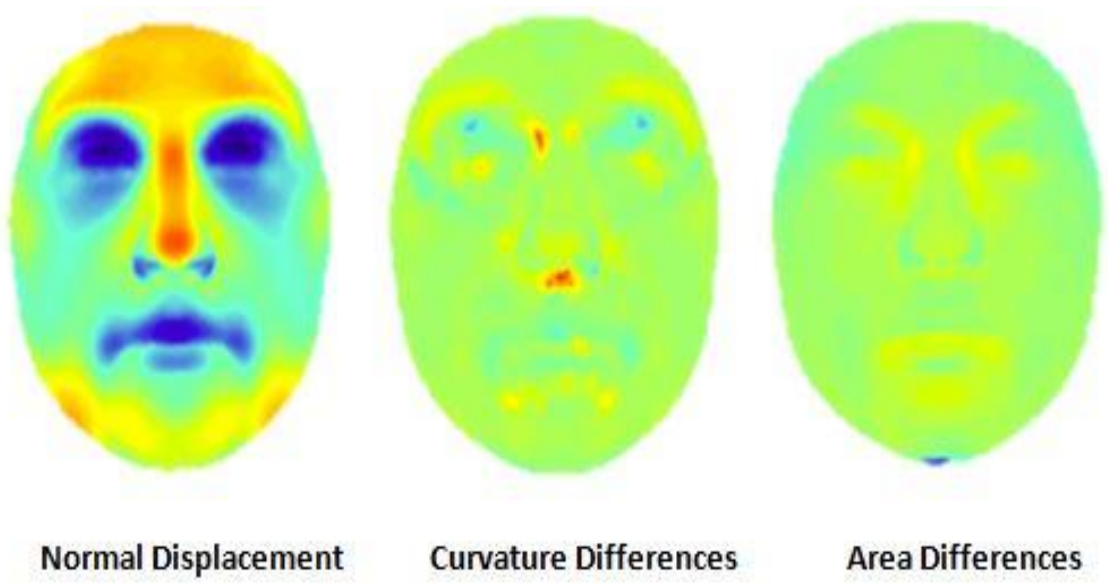

Figure 6: Heat maps for PC 30

PC 31 (Figure 7), which has significant positive correlations with both F_n and P_f in females has very strong signals of inward displacement in the lips with weaker signals in the maxillary regions and nares. Additionally, there are strong signals of outward displacement in the nasal bridge and chin. The philtrum and part of the chin appear to be more convex while the areas lateral to the lips appear to be more concave. There are few signs of area difference in the face with this PC except for weak signals suggesting larger surface area in regions lateral to the lips and surrounding the nasal bridge.

These positive correlations suggest that females with greater F_n and P_f would have more outward projecting lips and maxillary regions and more inward projecting nasal bridges and chins. While few differences in area are seen here, females with greater F_n and P_f show a slight decrease in the surface are of the regions surrounding the nasal bridge and the lips.

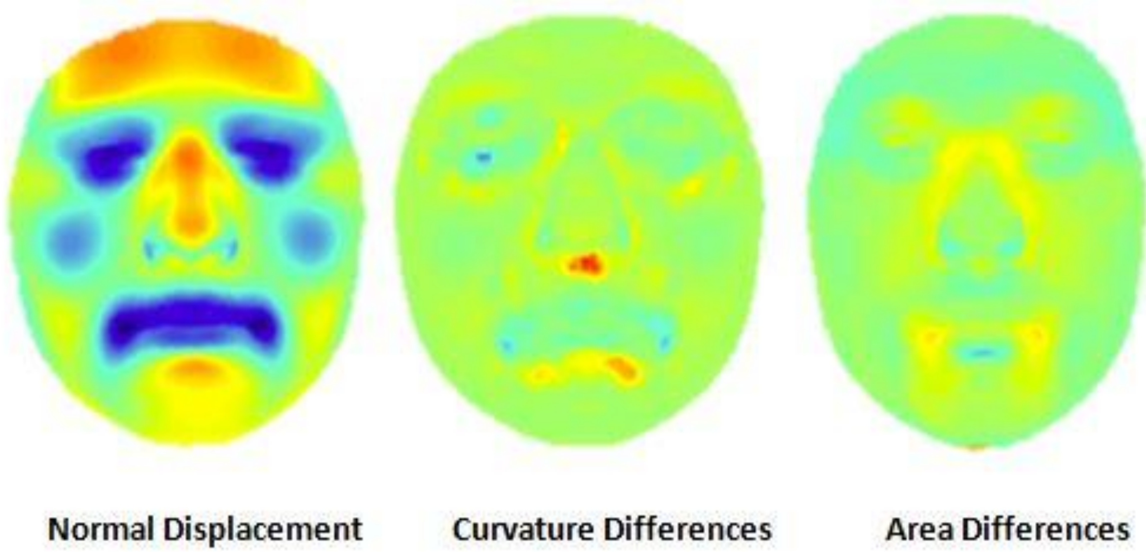

Figure 7: Heat maps for PC 31

PC 32 (Figure 8), which has a positive correlation with D_f in females, shows strong signals of outward displacement in the nasal bridge and mandibular regions in addition to strong signals of inward displacement in the areas surrounding the lips and nares. In curvature, there are smaller signals of convexity in the nares and lower lips, and concavity in the regions lateral of the lips. In area difference, there are strong signals suggesting greater surface area in the region of the nasal bridge, nares, and chin, while there are signs of lesser surface area in the lips.

The positive correlation between PC 32 and D_f here suggests that females with a greater D_f would have a more inward projecting nose, chin, and jaw in addition to more outward projecting lips, similar to the effect seen in the correlation between PC10 (Figure 5) and D_f.

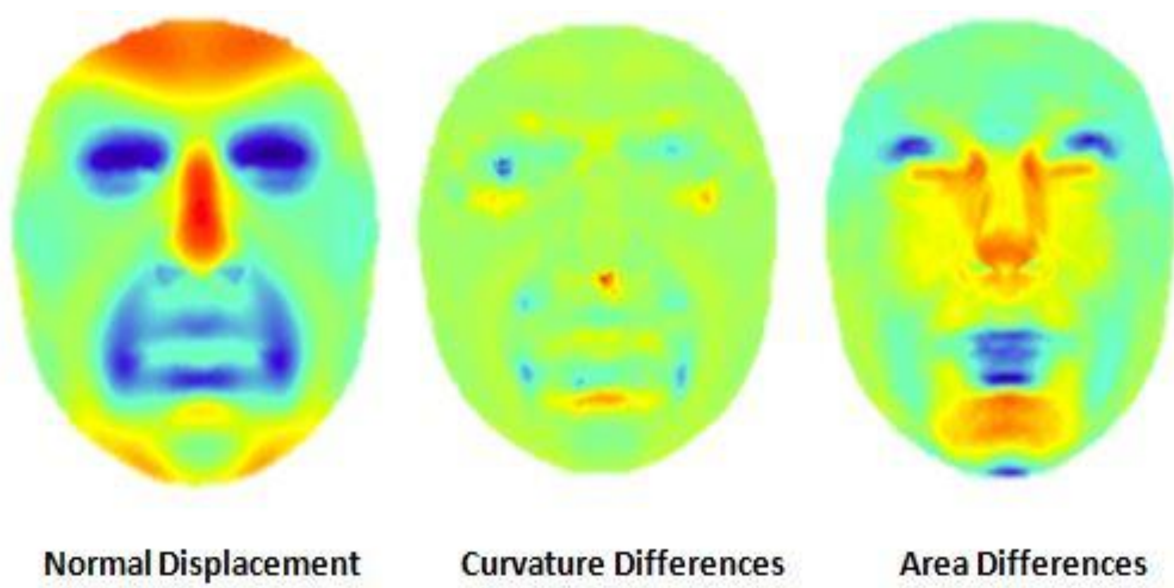

Figure 8: Heat maps for PC 32

Chapter 4

Discussion

High levels of sexual dimorphism among traits

Overall, almost every vocal and anthropometric trait examined here proved to be sexually dimorphic as the means of each differed significantly when compared using the Student's T test. Moreover, each one of the sexually dimorphic traits had large effect sizes based on Cohen's d's definitions for effect size (0.2 = small, 0.5 = medium, 0.8 = large; Cohen 1988).

Among the vocal traits, F_0 is the most sexually dimorphic with the largest effect size (Cohen's d = 5.39). F_n and the individual formants (F_1-F_4) all have very large effect sizes. Based on the effect size of the individual formants, F_1 and F_4 (Cohen's d = 3.18 and 3.14 respectively) seem to share similar levels of sexual dimorphism as do formants, F_2 and F_3 (Cohen's d = 2.50 and 2.73 respectively). However, this appears to be the only situation in which these formants share trends as their correlations with the body size traits do not follow suit. Because it is more difficult for humans to consciously differentiate among the individual formants, any reasons for which these traits became sexually dimorphic independent of F_0, which is more readily perceived, remain unclear. Speaker tonicity, F_0-Std, is not as sexually dimorphic as F_0. Perhaps, this lower level of sexual dimorphism in the variation in F_0 could be due to the necessity of the voice in both sexes to convey emotions more so than whichever signals that F_0 convey. Or, perhaps the structure of vocal tract or some other biological construct could limit the variation in F_0.

Nonetheless, even those traits with the weakest effect sizes of the sexually dimorphic vocal traits, F_0-Std and D_f, are still more than double the Cohen's d suggested cutoff for large effect size, thus suggesting a high degree of sexual dimorphism.

Among the anthropometric traits, foot length and hand strength appear to be the most sexually dimorphic traits (Cohen's d = 3.09 and 2.26 respectively). Height and sitting height are comparatively less sexually dimorphic (Cohen's d = 1.98 and 1.56 respectively). Weight is the least sexually dimorphic of all the anthropometric traits (Cohen's d = 0.76). Nonetheless, all these traits have a Cohen's d at least twice as large as the suggested cutoff for large effects.

The only traits which did not have significantly different means between the sexes were BMI and P_f. However, both of these traits are standardized values. BMI standardizes a person's weight by their height. P_f standardizes the individual formants by a z-score standardization separately by sex resulting in a mean of 0 for each sex. Therefore, these standardization methods most likely removed any signal of sexual dimorphism by scaling these traits.

Nonetheless, the fact that all of the mean differences which were significant at the 0.05 α level (i.e., those which were not standardized), remain significant at a Bonferroni corrected 0.0004 alpha level suggests that these differences are not artifacts of the number of statistical comparisons performed and are most likely biologically important. Therefore, it is reasonable to conclude that both the voice and body size have been under some sort of selection, most likely sexual selection. This could have occurred in both sexes, favoring larger males with a lower F_0 and smaller females with a higher F_0. Or perhaps, this could have occurred in just one sex, favoring either larger males with a lower F_0 or smaller females with a higher F_0.

There may, however, be several scenarios under which this has happened. One such scenario is that body size could have been under selection and consequently the sexual dimorphism in vocal traits could have developed as a result. However, given that the mean Cohen's d value for vocal traits is about 1.6 times larger than the mean Cohen's d value for body size traits, it is possible to speculate that vocal traits were the trait under selection and the sexual dimorphism in body size developed as a result.

For the objective face measurements, half of the PCs are sexually dimorphic but with small to medium effect sizes. Even after correcting for multiple tests, more than a quarter of the PCs remain significantly different. Nonetheless, these effect sizes are still considerably smaller than those for the vocal and body size traits. For example, body size traits are, on average, approximately 6.5 times more sexually dimorphic than the PCs based on Cohen's d effect sizes while vocal traits are, on average, approximately 10.5 times more sexually dimorphic.

Relationship between vocal traits and anthropometric measurements of body size

Due to the conflicting results from previously published studies, the relationship between vocal characteristics and anthropometric measurements, particularly those related to body size such as height, weight, and strength, remains unclear. However, a limitation of the majority of these previous studies has been small sample sizes. Consequently, a recent meta-analysis has offered population-level estimates of the correlation between these traits (Pisanski et al., 2014). One aim of this research is to further advance our knowledge of the relationship between vocal characteristics and anthropometrics by contributing larger population samples and more traits related to body size to the discussion.

Across the board, the significant correlations between the vocal traits and anthropometric measures of body size in both males and females are negative in direction. This suggests, for example, that individuals with lower F_0 values are taller than individuals with higher F_0 values, or that individuals with lower P_f scores are taller, heavier, stronger, and have larger feet on average than individuals with higher P_f scores.

Interestingly, these results provide further support to the hypothesis that formants offer more valuable insight into body size parameters than F_0. While F_0 has significant correlations with traits such as height and weight in both males and females, it does not have significant correlations with other traits such as hand strength, sitting height, foot length, or BMI in both males and females (Tables A4-A7). Additionally, when F_0 does correlate significantly with anthropometric measurements, the magnitude of these correlations is consistently half the size or smaller than the magnitude of the correlations with formant variables. Among the formant variables in particular, P_f and F_n seem to provide a higher frequency and higher magnitude of correlation with body size traits than D_f. P_f and F_n have significant correlations with every anthropometric trait of body size investigated here while the correlations between D_f and the body size traits are more sporadic.

Relationships between vocal traits and aspects of facial shape

While P_f and F_n show stronger correlations with body size traits, D_f has overall more significant correlations with various aspects of the face. This suggests that D_f is most strongly related to variation in superficial aspects of the face. However, various vocal traits are correlated with different face PCs in a pattern which is still unclear. While F_n and P_f seem to frequently correlate with the same PC, other traits such as F_0 or F_0-std do not share such patterns. This could imply that different regions of the face may be more linked to different aspects of the human voice.

Based on the correlations between the PCs and the vocal traits, it is reasonable to suggest that the magnitude of the FSCPs in the superficial aspects of the face involving the lips, chin, philtrum, nares, nasal bridge, and maxillary region could have an effect on the vocal traits of an individual. This adds to the previously studied effects of vocal tract length and thickness.

Among the FSCPs, it appears that differences in normal displacement and area have larger magnitudes in more areas of the face than differences in curvature do.

However, the exact nature of these effects remains somewhat unclear. While the trends between F_0 and the aspects of the face seem relatively consistent in both sexes, those between D_f and the aspects of the face diverge between males and females. In addition, some of the relationships seen in females appear to be opposite those seen in males depending on the PC analyzed. Nonetheless, only a few of the significant relationships between the vocal traits and the superficial traits characterized by the PCs were analyzed in this project. A more comprehensive analysis looking at all of the significant relationships would be the next step to clarify these relationships.

Indeed, it is important to note that the relationships between vocal parameters and superficial facial traits remain exploratory at this point. As seen under a Bonferroni correction, many of these values would no longer pass the significance threshold (Tables A8 and A9). In fact, only one correlation in males and three correlations in females would remain significant. Additionally, none of these facial PC correlations would be significant in both sexes. However, the trends in these correlations were consistent with those analyzed that were only seen at the 0.05 significance level.

Limitations

While much consideration was put into the design of the study, there were ultimately a few limitations or areas for improvement in future studies. For example, the sex ratio of the sample collected was skewed towards more females (63%:37%) which could have given the analyses within the traits of females more statistical power. Additionally, smoking behavior could have been considered earlier as an environmental factor which could have affected some of the vocal traits. Moreover, the area in which the voice recordings were collected ideally could have been more completely soundproofed. However, steps were taken later to account for this factor in the voice analysis portion of the study so it should not have been a major limitation.

Chapter 5

Conclusion

The data collected in this study provides evidence for sexual dimorphism and correlation between various traits. Many of the common traits related to the voice and to body size show strong signs of sexual dimorphism with large effect size. Moreover, the aspects of the face characterized by the PCs also show signs of sexual dimorphism. However, the degree of sexual dimorphism in these superficial traits is much smaller.

In addition, this data helps to clarify the relationship between vocal traits and anthropometric traits related to body size. While F_0 does show significant correlations with some characteristics of body size (e.g., height), F_n and P_f show both a greater number of significant correlations and a greater magnitude for each correlation with body size traits like height, weight, hand strength, sitting height, and foot length. Moreover, these correlations also pass a Bonferroni correction for multiple comparisons which strengthens their biological significance.

On the other hand, D_f has more frequent and stronger correlations with PCs of the face than with characteristics of body size. While many of these correlations and the correlations between the other vocal traits and face PCs do not pass Bonferroni correction, one correlation in males and three in females remain significant. These significant relationships present an area of future research to further investigate the functional relationship between these two variables.

These results offer a starting point to a better understanding of the relationships between the voice and the face from which investigators may conduct more comprehensive analyses of this data. Future analyses could also consider how covariation among traits may influence the correlation between traits and how these trait averages and correlations vary among ancestry groups. Once more of these underlying relationships are understood, multivariate regression models could be made to investigate the additive effects of all these variables.

In addition to collecting more data in humans, collecting data in model organisms such as dog breeds could help to better understand the morphometric and functional relationships between the superficial aspects of the face and the voice.

Appendix A
Supplemental Information

$$F_n = \frac{\sum_{i=1}^{n} F_i}{n}$$

Equation A1: Formula for Average Formant Frequency (F_n) taken from Pisanski *et al.*, 2014 where F_i is the *i*th formant frequency and n is the number of formants

$$D_f = \frac{\sum_{i=1}^{N-1} F_{i+1} - F_i}{N-1},$$

Equation A2: Formula for Formant Dispersion (D_f) taken from Fitch, 1997

$$P_f = \frac{\sum_{i=1}^{n} F_i'}{n},$$

Equation A3: Formula for Formant Position (P_f) taken from Puts *et al.*, 2011 where F'_i is the *i*th formant standardized using a z-score standardization (equation A4) and n is the number of formants.

$$F' = \frac{F_i - \mu_i}{\sigma}$$

Equation A4: Formula for z-score standardization where F_i is the *i*th formant, μ_i is the sample mean for the *i*th formant, and σ is the standard deviation of the sample mean

$$d = \frac{M_1 - M_2}{\sigma_{pooled}}$$

$$\text{Where: } \sigma_{pooled} = \sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}$$

EquationA5: Formula for Cohen's d where M_1 and M_2 are the means of each sample

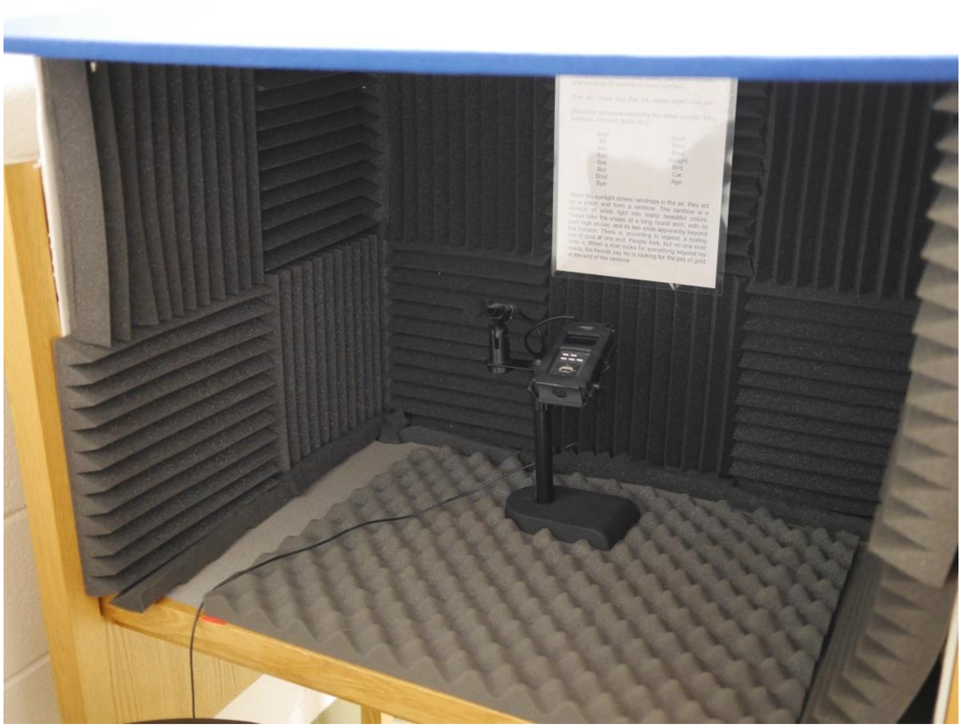

Figure A1: Set-up of the voice recording area

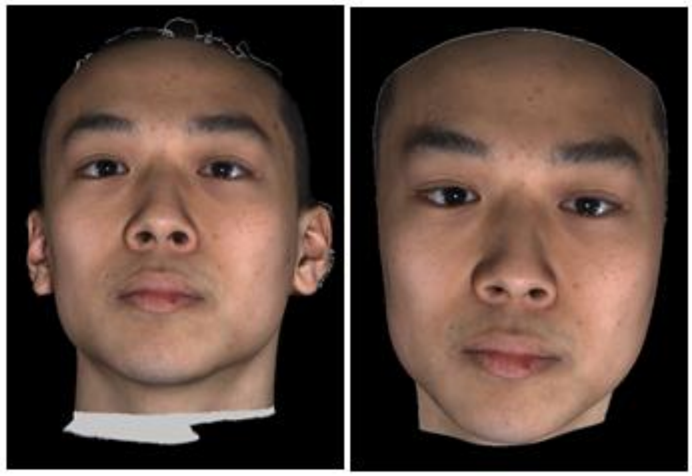

Figure A2: 3D facial image before (left) and after (right) scan-cleaning

Women's Size Conversions

US Sizes	Euro Sizes	UK Sizes	Inches	CM
4	35	2	8.1875"	20.8
4.5	35	2.5	8.375"	21.3
5	35-36	3	8.5"	21.6
5.5	36	3.5	8.75"	22.2
6	36-37	4	8.875"	22.5
6.5	37	4.5	9.0625"	23
7	37-38	5	9.25"	23.5
7.5	38	5.5	9.375"	23.8
8	38-39	6	9.5"	24.1
8.5	39	6.5	9.6875"	24.6
9	39-40	7	9.875"	25.1
9.5	40	7.5	10"	25.4
10	40-41	8	10.1875"	25.9
10.5	41	8.5	10.3125"	26.2
11	41-42	9	10.5"	26.7
11.5	42	9.5	10.6875"	27.1
12	42-43	10	10.875"	27.6

Men's Size Conversions

US Sizes	Euro Sizes	UK Sizes	Inches	CM
6	39	5.5	9.25"	23.5
6.5	39	6	9.5"	24.1
7	40	6.5	9.625"	24.4
7.5	40-41	7	9.75"	24.8
8	41	7.5	9.9375"	25.4
8.5	41-42	8	10.125"	25.7
9	42	8.5	10.25"	26
9.5	42-43	9	10.4375"	26.7
10	43	9.5	10.5625"	27
10.5	43-44	10	10.75"	27.3
11	44	10.5	10.9375"	27.9
11.5	44-45	11	11.125"	28.3
12	45	11.5	11.25"	28.6
13	46	12.5	11.5625"	29.4
14	47	13.5	11.875"	30.2
15	48	14.5	12.1875"	31
16	49	15.5	12.5"	31.8

Figure A3: Shoe size to cm conversion chart

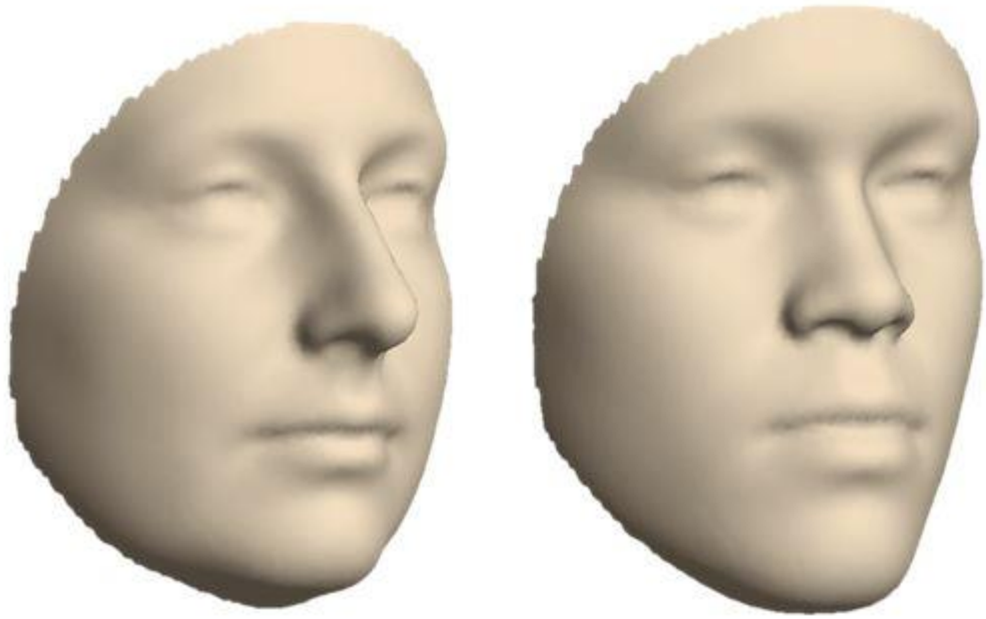

Figure A4: Model faces for PC4 showing the extremes of the PC axis (left = negative end; right = positive end)

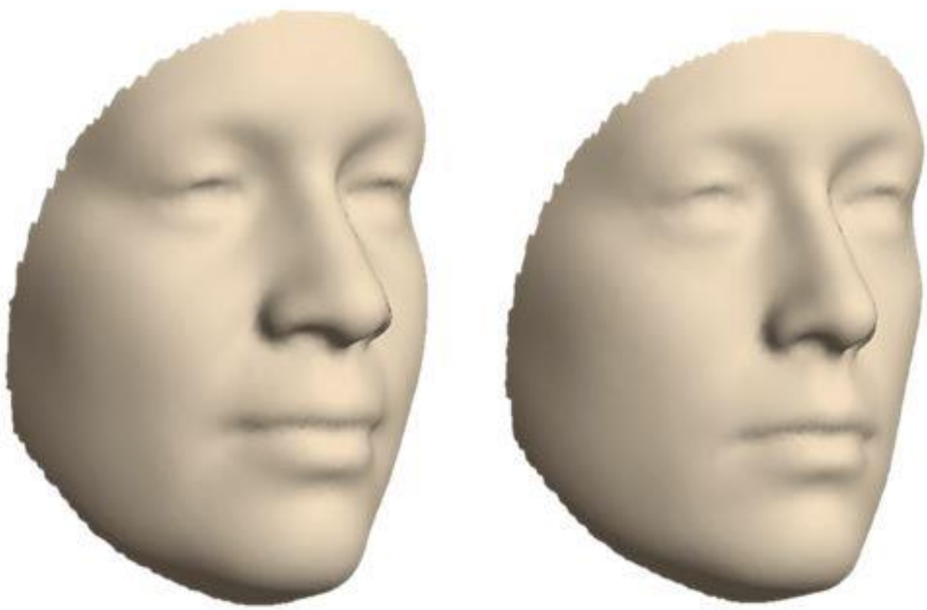

Figure A5: Model faces for PC8 showing the extremes of the PC axis (left = negative end; right = positive end)

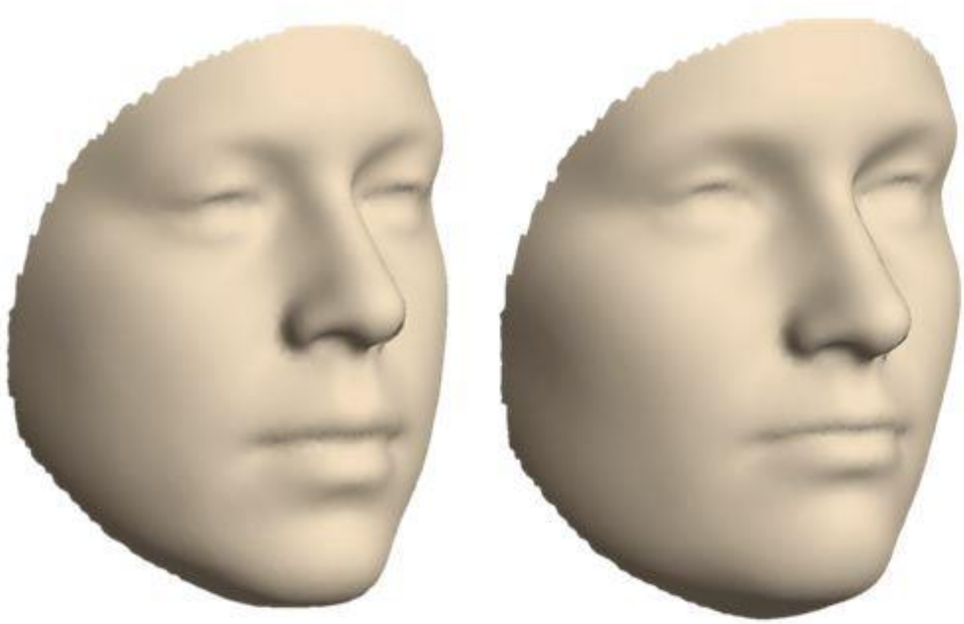

Figure A6: Model faces for PC10 showing the extremes of the PC axis (left = negative end; right = positive end)

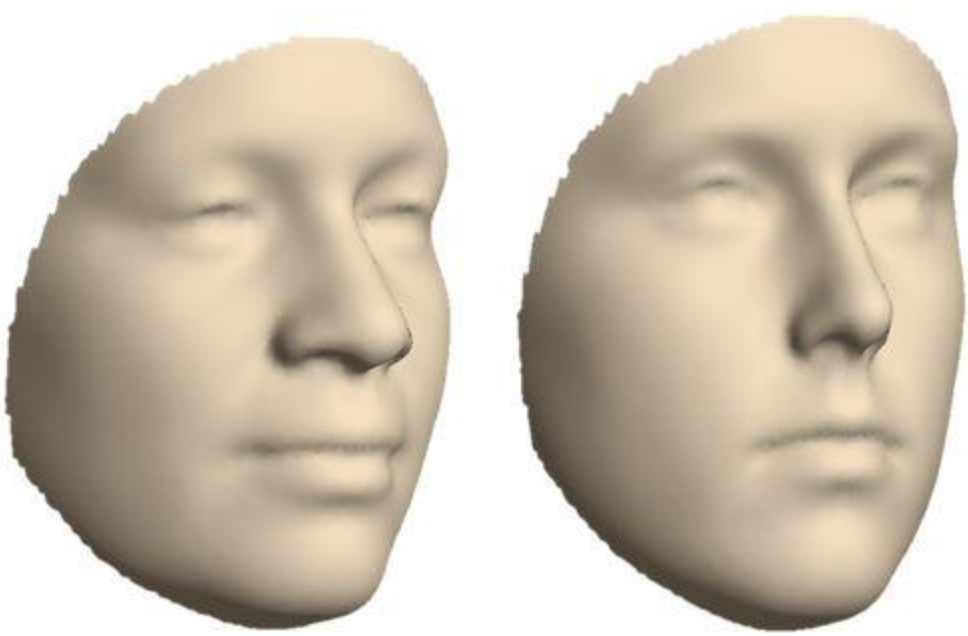

Figure A7: Model faces for PC11 showing the extremes of the PC axis (left = negative end; right = positive end)

Table A1: Voice Trait Averages

Measurement	Male		Female		t-value[t]	p-value	Cohen's d
	Mean	St. Dev.	Mean	St. Dev.			
F_0 (Hz)	109.71	13.89	199.07	19.00	79.47+	<0.0001*^	5.39
F_0-Std (Hz)	10.09	3.66	20.30	6.82	26.72+	<0.0001*^	1.87
F_1 (Hz)	431.44	45.35	608.74	64.65	46.74+	<0.0001*^	3.18
F_2 (Hz)	1509.86	61.29	1694.36	85.30	36.61+	<0.0001*^	2.50
F_3 (Hz)	2478.23	96.48	2757.99	108.32	41.25+	<0.0001*^	2.73
F_4 (Hz)	3442.68	131.03	3878.57	146.75	47.50+	<0.0001*^	3.14
F_n (Hz)	1965.55	58.30	2234.91	68.42	63.90+	<0.0001*^	4.25
D_f (Hz)	1003.75	48.07	1089.94	51.81	26.77#	<0.0001*^	1.73
P_f (Hz)	0.00	0.64	0.00	0.62	N/A	N/A	N/A

t: t-value generated from Student's t-test
+ equal variance based on results of F-test for equality of variance
 # unequal variance based on results of F-test for equality of variance
*** significant at p <0.05, normal α value**
^ significant at p < 0.000431, Bonferroni corrected α value

Table A2: Anthropometric Trait Averages

Measurement	Male		Female		t-value[t]	p-value	Cohen's d
	Mean	St. Dev.	Mean	St. Dev.			
Height (cm)	176.70	7.11	163.68	6.19	-30.09+	<0.0001*^	1.98
Weight (kg)	79.01	15.42	67.22	15.91	-11.63#	<0.0001*^	0.76
BMI (kg/cm^2)	25.27	4.49	25.05	5.59	-0.65+	0.52	0.04
Sitting Height (cm)	92.79	4.04	86.98	3.45	-24.44+	<0.0001*^	1.56
Hand Strength (kg of force)	43.11	8.62	27.13	5.29	-36.69+	<0.0001*^	2.26
Foot Length (cm)	27.67	1.21	24.24	1.01	-47.23+	<0.0001*^	3.09

t: t-value generated from Student's t-test
+ equal variance based on results of F-test for equality of variance
 # unequal variance based on results of F-test for equality of variance
*** significant at p <0.05, normal α value**
^ significant at p < 0.000431, Bonferroni corrected α value

Table A3: Face PC Averages

Measurement	Male		Female		t-value	p-value	Cohen's d
	Mean	St. Dev.	Mean	St. Dev.			
PC1	0.59	0.86	-0.39	0.87	-17.12[#]	<0.0001*^	1.13
PC2	-0.11	0.70	0.02	0.68	2.70[#]	<0.01*	0.18
PC3	0.70	0.90	-0.22	0.88	-15.61[#]	<0.0001*^	1.04
PC4	0.05	0.91	-0.10	0.97	-2.35[#]	0.02*	0.15
PC5	-0.31	0.88	0.17	0.88	8.11[#]	<0.0001*^	0.54
PC6	-0.38	0.96	-0.09	0.89	4.74[#]	<0.0001*^	0.32
PC7	-0.01	0.95	0.36	0.94	5.76[#]	<0.0001*^	0.38
PC8	0.003	0.92	0.09	0.93	1.48[#]	0.14	0.10
PC9	0.78	0.78	0.36	0.80	-8.17[#]	<0.0001*^	0.54
PC10	-0.12	0.83	-0.0008	0.97	1.99[+]	<0.05*	0.13
PC11	0.13	0.85	0.12	0.97	-0.12[+]	0.90	0.01
PC12	0.28	0.95	0.11	0.94	-2.83[#]	<0.01*	0.19
PC13	-0.01	0.92	-0.22	0.84	-3.54[#]	<0.001*	0.24
PC14	-0.18	0.94	0.30	0.92	7.77[#]	<0.0001*^	0.52
PC15	0.10	0.93	0.12	0.95	0.31[#]	0.75	0.02
PC16	0.50	0.84	0.95	0.79	8.29[#]	<0.0001*^	0.56
PC17	-0.48	0.92	-0.19	0.89	4.81[#]	<0.0001*^	0.32
PC18	0.17	0.93	0.03	0.89	-2.24[#]	0.03*	0.15
PC19	-0.11	0.87	-0.14	0.93	-0.50[#]	0.62	0.03
PC20	0.24	1.02	0.005	0.94	-3.51[#]	<0.001*	0.24
PC21	0.03	0.92	0.09	0.91	1.02[#]	0.31	0.07
PC22	-0.007	0.95	0.22	0.91	3.62[#]	0.0003*^	0.24
PC23	-0.10	1.05	0.12	0.89	3.59[+]	<0.001*	0.24
PC24	-0.40	0.85	-0.15	0.88	4.46[#]	<0.0001*^	0.29
PC25	-0.18	1.00	-0.21	0.85	-0.53[+]	0.60	0.04
PC26	-0.42	0.95	-0.09	0.88	5.16[#]	<0.0001*^	0.35
PC27	-0.05	1.02	0.05	0.89	1.72[+]	0.09	0.11
PC28	-0.10	0.94	-0.09	0.85	0.26[+]	0.80	0.02
PC29	0.38	0.95	0.17	0.86	-3.55[+]	0.0004*^	0.24
PC30	-0.16	0.95	0.10	0.94	4.24[#]	<0.0001*^	0.28
PC31	0.04	0.92	-0.09	0.85	-2.21[#]	0.03*	0.15
PC32	-0.14	0.82	-0.41	0.90	-4.69[#]	<0.0001*^	0.30
PC33	-0.16	0.62	-0.004	0.68	3.64[#]	0.0003*^	0.24
PC34	0.03	0.98	0.10	0.83	1.05[+]	0.29	0.07
PC35	-0.28	1.0	0.01	0.90	4.68[+]	<0.0001*^	0.31
PC36	-0.14	0.85	-0.09	0.85	0.98[#]	0.33	0.07
PC37	0.02	0.89	-0.03	0.82	-0.83[#]	0.41	0.06

PC38	0.0002	0.93	0.002	0.89	0.03$^{\#}$	0.98	0.002
PC39	0.07	0.86	-0.07	0.79	-2.66$^{\#}$	<0.01*	0.18
PC40	0.05	0.98	-0.12	0.86	-2.76^{+}	<0.01*	0.18
PC41	0.14	0.98	0.12	0.86	-0.19^{+}	0.85	0.01
PC42	-0.14	0.97	-0.01	0.83	2.26^{+}	0.02*	0.15
PC43	-0.23	0.90	-0.17	0.92	1.02$^{\#}$	0.31	0.07
PC44	-0.03	0.94	0.02	0.90	0.94$^{\#}$	0.34	0.06
PC45	-0.08	0.82	-0.07	0.76	0.17$^{\#}$	0.87	0.01
PC46	-0.03	0.91	-0.04	0.82	-0.25^{+}	0.80	0.02
PC47	-0.02	0.91	-0.008	0.80	0.27^{+}	0.79	0.02
PC48	0.05	0.78	0.14	0.81	1.69$^{\#}$	0.09	0.01
PC49	-0.03	0.91	0.08	0.85	1.94$^{\#}$	0.05	0.13
PC50	-0.22	0.82	-0.13	0.80	1.66$^{\#}$	0.10	0.11
PC51	0.03	0.89	0.11	0.85	1.49$^{\#}$	0.14	0.10
PC52	-0.10	0.87	0.10	0.79	3.75$^{\#}$	0.0002*^	0.25
PC53	-0.03	0.86	-0.18	0.88	-2.64$^{\#}$	<0.01*	0.17
PC54	-0.05	0.88	-0.14	0.84	-1.46$^{\#}$	0.14	0.10
PC55	-0.005	0.91	-0.03	0.86	-0.43$^{\#}$	0.67	0.03
PC56	-0.01	0.71	-0.07	0.72	-1.12$^{\#}$	0.26	0.07
PC57	0.19	0.80	0.05	0.76	-2.75$^{\#}$	<0.01*	0.19
PC58	-0.07	0.83	-0.17	0.90	-1.88$^{\#}$	0.06	0.12
PC59	-0.08	0.87	-0.23	0.81	-2.75$^{\#}$	<0.01*	0.19
PC60	0.10	0.79	-0.18	0.78	-5.47$^{\#}$	<0.0001*^	0.36
PC61	0.12	0.80	-0.04	0.75	-3.11$^{\#}$	<0.01*	0.21
PC62	-0.03	0.85	0.05	0.82	1.36$^{\#}$	0.17	0.09
PC63	-0.10	0.91	-0.07	0.78	0.52^{+}	0.60	0.03
PC64	0.05	0.94	0.05	0.86	0.04$^{\#}$	0.97	0.003
PC65	0.09	0.88	-0.008	0.78	-1.80^{+}	0.07	0.12
PC66	-0.003	0.91	-0.05	0.87	-0.74$^{\#}$	0.46	0.05
PC67	0.12	0.83	-0.03	0.81	-2.72$^{\#}$	<0.01*	0.18
PC68	-0.04	0.88	-0.10	0.80	-1.08^{+}	0.28	0.07
PC69	0.03	0.82	0.08	0.82	0.90$^{\#}$	0.37	0.06
PC70	0.02	0.83	-0.04	0.79	-1.15$^{\#}$	0.25	0.08
PC71	0.09	0.69	-0.03	0.67	-2.65$^{\#}$	<0.01*	0.18
PC72	-0.004	0.83	-0.04	0.76	-0.60$^{\#}$	0.55	0.04
PC73	-0.13	0.96	0.01	0.80	2.45^{+}	0.01*	0.16
PC74	-0.16	0.78	-0.06	0.74	1.99$^{\#}$	<0.05*	0.14
PC75	0.01	0.74	-0.03	0.73	-0.81$^{\#}$	0.42	0.05
PC76	0.09	0.92	-0.03	0.81	-2.00^{+}	<0.05*	0.13
PC77	0.007	0.90	-0.06	0.82	-1.20^{+}	0.23	0.08
PC78	-0.01	0.77	-0.003	0.74	0.17$^{\#}$	0.87	0.01
PC79	-0.02	0.84	0.06	0.77	1.63$^{\#}$	0.10	0.11

PC80	-0.07	0.78	-0.05	0.73	0.38#	0.70	0.03
PC81	-0.14	0.79	-0.10	0.77	0.75#	0.45	0.05
PC82	-0.02	0.79	0.06	0.76	1.58#	0.12	0.11
PC83	0.25	0.91	-0.12	0.75	-6.90+	<0.0001*^	0.46
PC84	-0.05	0.83	-0.06	0.77	-0.19#	0.85	0.01
PC85	0.03	0.77	-0.08	0.76	-2.10#	0.04*	0.14
PC86	-0.11	0.68	0.06	0.71	3.65#	0.0003*^	0.24
PC87	0.07	0.79	-0.13	0.72	-4.00#	<0.0001*^	0.27
PC88	0.14	0.87	0.03	0.81	-1.95#	0.05	0.13
PC89	0.009	0.87	-0.23	0.78	-4.44+	<0.0001*^	0.29
PC90	0.09	0.69	-0.08	0.67	-3.81#	0.0002*^	0.25
PC91	0.22	0.83	-0.05	0.80	-5.07#	<0.0001*^	0.34
PC92	0.03	0.79	0.05	0.74	0.40#	0.69	0.03
PC93	0.14	0.83	-0.14	0.75	-5.39+	<0.0001*^	0.36
PC94	-0.06	0.83	-0.02	0.74	0.73+	0.50	0.05
PC95	-0.07	0.86	0.13	0.82	3.47#	<0.001*	0.23
PC96	0.07	0.82	0.03	0.72	-0.66+	0.51	0.04
PC97	0.14	0.79	0.15	0.69	0.16+	0.87	0.01
PC98	0.14	0.74	0.11	0.67	-0.58+	0.56	0.04
PC99	0.01	0.79	0.10	0.76	1.64#	0.10	0.11
PC100	-0.15	0.85	-0.02	0.80	2.28#	0.02*	0.15

t: t-value generated from Student's t-test
+ equal variance based on results of F-test for equality of variance
 # unequal variance based on results of F-test for equality of variance
*** significant at p <0.05, normal α value**
^ significant at p < 0.000431, Bonferroni corrected α value

Table A4: Correlation values for male vocal traits and anthropometric measurements

	Height			Weight		
	r	**p**	**n**	**r**	**P**	**n**
F_0	-0.14*	<0.01	371	-0.03	0.62	368
F_0 - Std	-0.04	0.43	371	0.065	0.21	368
F_1	-0.12*	0.02	371	-0.13*	0.01	368
F_2	-0.22*^	<0.0001	371	-0.13*	0.01	368
F_3	-0.18*	0.00	371	-0.11*	0.04	368
F_4	-0.20*^	<0.0001	371	-0.22*	<0.0001	368
F_n	-0.27*^	<0.0001	371	-0.23*	<0.0001	368
D_F	-0.15*	0.00	371	-0.16*	0.00	368
P_F	-0.29*^	<0.0001	371	-0.23*^	<0.0001	368

*** p < 0.05**
^ p < 0.000431, Bonferroni corrected α value

Table A5: Correlation values for male vocal traits and other anthropometric measurements

	Sitting Height			Hand Strength			BMI			Foot Length		
	r	**p**	**n**	**r**	**p**	**n**	**r**	**p**	**n**	**r**	**p**	**n**
F_0	-0.10	0.05	371	-0.07	0.16	365	0.04	0.41	368	-0.10	0.06	356
F_0 - Std	0.01	0.85	371	-0.12*	0.02	365	0.9	0.07	368	-0.01	0.8	356
F_1	-0.06	0.22	371	-0.07	0.19	365	-0.10	0.05	368	-0.16*	<0.01	356
F_2	-0.24*^	<0.0001	371	-0.19*	0.00	365	-0.04	0.40	368	-0.20*	<0.001	356
F_3	-0.17*	0.00	371	-0.21*^	<0.0001	365	-0.04	0.49	368	-0.22^*	<0.0001	356
F_4	-0.18*	0.00	371	-0.09	0.07	365	-0.15*	<0.01	368	-0.20*	<0.001	356
F_n	-0.25*^	<0.0001	371	-0.20*	<0.001	365	-0.13*	0.01	368	-0.29*^	<0.0001	356
D_f	-0.15*	0.01	371	-0.06	0.22	365	-0.10*	0.04	368	-0.13*	0.01	356
P_f	-0.26*^	<0.0001	371	-0.22*^	<0.0001	365	-0.13*	0.01	368	-0.30*^	<0.0001	356

*** $p < 0.05$**
^ $p < 0.000431$, Bonferroni corrected α value

Table A6: Correlation values for female vocal traits and classic anthropometric measurements

	Height			Weight		
	r	**p**	**n**	**r**	**p**	**n**
F_0	-0.14*	<0.001	642	-0.09*	0.02	642
F_0 - Std	-0.05	0.22	642	0.01	0.80	640
F_1	-0.16*^	<0.0001	642	-0.17*^	<0.0001	642
F_2	-0.05	0.22	642	-0.18*^	<0.0001	642
F_3	-0.12*	0.00	642	-0.15*^	<0.0001	642
F_4	-0.10*	0.01	642	-0.29*^	<0.0001	642
F_n	-0.15*^	<0.0001	642	-0.31*^	<0.0001	642
D_f	-0.02	0.54	642	-0.20*^	<0.0001	642
P_f	-0.17*^	<0.0001	642	-0.32*^	<0.0001	642

*** $p < 0.05$, normal α value**
^ $p < 0.000431$, Bonferroni corrected α value

Table A7: Correlation values for female vocal traits and other anthropometric measurements

	Sitting Height			Hand Strength			BMI			Foot Length		
	r	**p**	**n**	**r**	**p**	**n**	**r**	**p**	**n**	**r**	**p**	**n**
F_0	-0.04	0.34	640	-0.04	0.32	631	-0.05	0.22	640	-0.12*	<0.01	544
F_0 - Std	-0.04	0.30	640	-0.04	0.28	631	0.03	0.46	640	-0.06	0.14	544
F_1	-0.14*^	<0.001	640	-0.16*^	<0.0001	631	-0.13*	<0.01	640	-0.16*	<0.001	544
F_2	-0.06	0.14	640	-0.2	0.63	631	-0.17*^	<0.0001	640	-0.12*	<0.01	544
F_3	-0.13*	<0.01	640	-0.01	0.71	631	-0.12*	<0.01	640	-0.10*	0.02	544
F_4	-0.10*	<0.01	640	-0.09*	0.02	631	-0.27*^	<0.0001	640	-0.15*^	<0.0001	544
F_n	-0.16*^	<0.0001	640	-0.10*	0.01	631	-0.27*^	<0.0001	640	-0.19*^	<0.0001	544
D_f	-0.04	0.33	640	-0.02	0.64	631	-0.20*^	<0.0001	640	-0.08	0.07	544
P_f	-0.17*^	<0.0001	640	-0.12*	<0.01	631	-0.28*^	<0.0001	640	-0.21*^	<0.0001	544

*** $p < 0.05$**

^ $p < 0.000431$, Bonferroni corrected α value

Table A8: Significant correlation values for male vocal traits and normalized face PCs

PC	N	F_0		F_0 – Std		F_n		D_f		P_f	
		r	p	r	p	r	P	r	P	r	p
1	360			-0.11	0.04						
4	360	-0.16	<0.01	-0.12	0.02						
6	360			0.12	0.02			-0.13	0.02		
7	360					-0.12	0.03	-0.12	0.02		
8	360							-0.14	<0.01		
10	360					-0.11	0.03	-0.14	<0.01		
11	360	0.20	<0.001								
14	360					0.12	0.03	0.13	0.01		
16	360							0.13	0.01		
22	360			-0.15	<0.01						
24	360							0.11	0.04		
28	360									-0.13	0.01
30	360							-0.22^	<0.0001		
34	360					0.11	0.03			0.11	<0.05
35	360					0.11	0.03			0.12	0.03
41	360			0.12	0.03						
45	360					0.15	<0.01	0.14	<0.01	0.12	0.02
47	360							0.10	0.05		
50	360							-0.11	0.04		
52	360							0.14	<0.01		
57	360					0.14	<0.01	0.11	0.03	0.13	0.02
59	360							0.14	<0.01		
63	360					0.12	0.03			0.11	0.04
67	360			-0.13	0.01						
71	360			0.13	0.01						
72	360					0.14	<0.01			0.13	0.01
75	360			-0.11	0.03						
77	360	-0.11	0.04								
78	360			0.11	0.03			-0.12	0.03		
84	360			-0.13	0.01						
91	360			-0.14	<0.01						
92	360					0.12	0.02	0.11	0.04	0.11	0.03
93	360							0.11	0.04		
95	360							0.14	<0.01		
97	360			0.14	<0.01						
Total		3		12		10		18		8	

^ significant at $p < 0.000431$, Bonferroni corrected α value

Table A9: Significant correlation values for female vocal traits and normalized face PCs

PC	N	F_0		F_0 – Std		F_n		D_f		P_f	
		r	p	r	p	r	p	r	p	r	p
1	623							0.10	<0.01		
2	623			0.09	0.03	-0.10	0.01	-0.13	<0.01	-0.09	0.03
3	623	0.09	0.02								
4	623	-0.12	<0.01								
5	623	0.13	<0.01			0.13	<0.01			0.15	<0.001
6	623					-0.13	<0.001			-0.15	<0.001
8	623			0.08	0.03	-0.13	<0.001	-0.10	<0.01	-0.13	<0.01
9	623			-0.08	0.04			-0.15	<0.001		
10	623							0.15	<0.001		
11	623	0.13	<0.001								
15	623							-0.08	0.04		
17	623			0.09	0.02	0.12	<0.01			0.14	<0.001
19	623	0.14	<0.001			0.09	0.02	0.13	<0.01	0.08	0.05
20	623			0.10	0.01						
28	623					-0.13	<0.01	-0.15	<0.001	-0.11	<0.01
31	623					0.18^	<0.0001	0.14	<0.001	0.17^	<0.0001
32	623							0.19^	<0.0001		
35	623	-0.09	0.02								
36	623					0.09	0.02			0.10	0.01
37	623			0.09	0.02			0.10	0.01		
38	623							-0.10	0.01		
39	623							0.09	0.03	-0.11	<0.01
40	623			-0.08	<0.05	0.17^	<0.0001	0.12	<0.01	0.17^	<0.0001
44	623					-0.11	<0.01			-0.11	<0.01
46	623	0.11	<0.01	0.11	<0.01			0.11	<0.01		
48	623					0.09	0.02	0.09	0.02		
49	623			0.12	<0.01						
53	623							-0.11	<0.01		
56	623	-0.09	0.03					-0.10	0.01		
57	623	0.10	0.02								
58	623	0.08	0.04							0.09	0.03
59	623							-0.11	<0.01		
60	623	-0.11	<0.01					-0.11	<0.01		
62	623							0.09	0.03		
65	623					-0.12	<0.01			-0.12	<0.01
69	623							0.11	<0.01		
73	623							0.11	<0.01		
75	623			-0.09	0.03						
79	623					0.09	0.02	0.08	<0.05	0.09	0.02
80	623							0.11	<0.01		
81	623							-0.11	<0.01		
82	623	-0.08	0.04							-0.09	0.02
87	623							-0.11	<0.01		
91	623			0.09	0.03						
94	623					-0.16	<0.001	-0.13	<0.001	-0.15	<0.001
Total		12		11		15		28		17	

^ significant at $p < 0.000431$, Bonferroni corrected α value

Appendix B
Scripts and Protocols

Today is {day, month, date, year}. I am {male/female} and my study ID number is {your number}.

One, two, three, four, five, six, seven, eight, nine, ten.

{Read the list below extending the vowel sounds, for example, beeeeet, biiiiiit, etc.}

Beet	Book
Bit	Boot
Bet	Boat
Bait	Bought
Bat	Bird
But	Car
Bout	Ago
Bye	

When the sunlight strikes raindrops in the air, they act as a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Figure B1: Voice Recording Script

```
#Male voice F0

clearinfo

directory_get$ = chooseDirectory$ ("Choose a direcory")

Create Strings as file list...  list 'directory_get$'/*.WAV
number_of_files = Get number of strings

echo fileName'tab$'duration'tab$'medPitch'tab$'meanPitch'tab$'minPitch'tab$'maxPitch'tab$'
sdPitch'tab$'voiceBreaks'tab$'jitter'tab$'jitterRap'tab$'jitterPpq5'tab$'jitterDdq'tab$'shimmer
'tab$'shimmerApq3'tab$'shimmerApq5'tab$'shimmerApq11'tab$'shimmerDda'tab$'harmonics'newline$'


for x to number_of_files

     select Strings list
     Sort
        current_file$ = Get string... x
                current_file2$ = replace$ (current_file$, ".WAV", "", 0)
                Read from file... 'directory_get$'/'current_file$'

                select Sound 'current_file2$'
                Extract one channel... Left

                To Pitch (cc)...  0 75 15 no  0.03 0.6 0.01 0.7 0.3 300
                select Sound 'current_file2$'_ch1
                plus Pitch 'current_file2$'_ch1
                To PointProcess (cc)
                select Sound 'current_file2$'_ch1
                plus Pitch 'current_file2$'_ch1
                plus PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                voiceReport$ = Voice report... 0 0 75 300 1.3 1.6 0.03 0.45

                duration = extractNumber (voiceReport$, "duration: ")

                medPitch =extractNumber (voiceReport$, "Median pitch: ")
                meanPitch =extractNumber (voiceReport$, "Mean pitch: ")
                minPitch =extractNumber (voiceReport$, "Minimum pitch: ")
                maxPitch =extractNumber (voiceReport$, "Maximum pitch: ")
                sdPitch =extractNumber (voiceReport$, "Standard deviation: ")

                voiceBreaks =extractNumber (voiceReport$, "Number of voice breaks: ")

                jitter = extractNumber (voiceReport$, "Jitter (local): ")
                jitterRap =extractNumber (voiceReport$, "Jitter (rap): ")
                jitterPpq5 =extractNumber (voiceReport$, "Jitter (ppq5): ")
                jitterDdq =extractNumber (voiceReport$, "Jitter (ddp): ")

                shimmer = extractNumber (voiceReport$, "Shimmer (local): ")
                shimmerApq3 = extractNumber (voiceReport$, "Shimmer (apq3): ")
                shimmerApq5 = extractNumber (voiceReport$, "Shimmer (apq5): ")
                shimmerApq11 = extractNumber (voiceReport$, "Shimmer (apq11): ")
                shimmerDda = extractNumber (voiceReport$, "Shimmer (dda): ")

                harmonics = extractNumber (voiceReport$, "Mean harmonics-to-noise ratio: ")

                print 'current_file2$''tab$''duration''tab$''medPitch''tab$''meanPitch''tab$''minPitch'
                'tab$''maxPitch''tab$''sdPitch''tab$''voiceBreaks''tab$''jitter''tab$''jitterRap''tab$'
                'jitterPpq5''tab$''jitterDdq''tab$''shimmer''tab$''shimmerApq3''tab$''shimmerApq5''tab$'
                'shimmerApq11''tab$''shimmerDda''tab$''harmonics''newline$'
        Remove
endfor
select all
```

Figure B2: Praat script for male F0

```
#female voice F0

clearinfo

directory_get$ = chooseDirectory$ ("Choose a directory")

Create Strings as file list...  list 'directory_get$'/*.WAV
number_of_files = Get number of strings

echo fileName'tab$'duration'tab$'medPitch'tab$'meanPitch'tab$'minPitch'tab$'maxPitch'tab$'sdPitch'tab$'voiceBreak
'tab$'jitter'tab$'jitterRap'tab$'jitterPpq5'tab$'jitterDdq'tab$'shimmer'tab$'shimmerApq3'tab$'shimmerApq5'tab$'
shimmerApq11'tab$'shimmerDda'tab$'harmonics'newline$'

for x to number_of_files

    select Strings list
     Sort
        current_file$ = Get string... x
                current_file2$ = replace$ (current_file$, ".WAV", "", 0)
                Read from file...  'directory_get$'/'current_file$'

                select Sound 'current_file2$'
                Extract one channel... Left

                To Pitch (cc)...  0 150 15 no  0.03 0.6 0.01 0.7 0.3 350
                select Sound 'current_file2$'_ch1
                plus Pitch 'current_file2$'_ch1
                To PointProcess (cc)
                select Sound 'current_file2$'_ch1
                plus Pitch 'current_file2$'_ch1
                plus PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                voiceReport$ = Voice report... 0 0 100 500 1.3 1.6 0.03 0.45

                duration = extractNumber (voiceReport$, "duration: ")

                medPitch =extractNumber (voiceReport$, "Median pitch: ")
                meanPitch =extractNumber (voiceReport$, "Mean pitch: ")
                minPitch =extractNumber (voiceReport$, "Minimum pitch: ")
                maxPitch =extractNumber (voiceReport$, "Maximum pitch: ")
                sdPitch =extractNumber (voiceReport$, "Standard deviation: ")

                voiceBreaks =extractNumber (voiceReport$, "Number of voice breaks: ")

                jitter = extractNumber (voiceReport$, "Jitter (local): ")
                jitterRap =extractNumber (voiceReport$, "Jitter (rap): ")
                jitterPpq5 =extractNumber (voiceReport$, "Jitter (ppq5): ")
                jitterDdq =extractNumber (voiceReport$, "Jitter (ddp): ")

                shimmer = extractNumber (voiceReport$, "Shimmer (local): ")
                shimmerApq3 = extractNumber (voiceReport$, "Shimmer (apq3): ")
                shimmerApq5 = extractNumber (voiceReport$, "Shimmer (apq5): ")
                shimmerApq11 = extractNumber (voiceReport$, "Shimmer (apq11): ")
                shimmerDda = extractNumber (voiceReport$, "Shimmer (dda): ")

                harmonics = extractNumber (voiceReport$, "Mean harmonics-to-noise ratio: ")

                print 'current_file2$''tab$''duration''tab$''medPitch''tab$''meanPitch''tab$''minPitch''tab$'
                'maxPitch''tab$''sdPitch''tab$''voiceBreaks''tab$''jitter''tab$''jitterRap''tab$''jitterPpq5'
                'tab$''jitterDdq''tab$''shimmer''tab$''shimmerApq3''tab$''shimmerApq5''tab$''shimmerApq11''tab$'
                'shimmerDda''tab$''harmonics''newline$'
        Remove
endfor
select all
Remove
```

Figure B3:Praat script for female F0

```
#Male voices formants

clearinfo

directory_get$ = chooseDirectory$ ("Choose a directory")

Create Strings as file list...  list 'directory_get$'/*.WAV
number_of_files = Get number of strings

echo fileName'tab$'F1'tab$'F2'tab$'F3'tab$'F4'tab$'errors'tab$'points'newline$'

for x to number_of_files
     select Strings list
     Sort
        current_file$ = Get string... x
                current_file2$ = replace$ (current_file$, ".WAV", "", 0)
                Read from file... 'directory_get$'/'current_file$'

                select Sound 'current_file2$'
                Extract one channel... Left

                i = 1
                numPoints = 0
                sumF1 = 0
                avF1 = 0
                sumF2 = 0
                avF2 = 0
                sumF3 = 0
                avF3 = 0
                sumF4 = 0
                avF4 = 0
                errors = 0

                To Pitch (cc)...  0 75 15 no  0.03 0.6 0.01 0.7 0.3 300
                select Sound 'current_file2$'_ch1
                plus Pitch 'current_file2$'_ch1
                To PointProcess (cc)
                select Sound 'current_file2$'_ch1
                To Formant (burg)... 0.0025 5 5000 0.025 50
                select PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                numPoints=Get number of points

                for i to numPoints
                        status = 0
                        select PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                        t = Get time from index... 'i'

                        select Formant 'current_file2$'_ch1
                        f1 = Get value at time... 1 't' Hertz Linear
                        f2 = Get value at time... 2 't' Hertz Linear
                        f3 = Get value at time... 3 't' Hertz Linear
                        f4 = Get value at time... 4 't' Hertz Linear


                if f4 = undefined
                        status = 1
                else
                        if f1 > 1000
                                status = 1
                        else

                                if f2 > 2850
                                        status = 1
                                else

                                        if f3 > 3750
                                                status = 1
                                        else

                                                if f4 > 4500
                                                        status = 1
                                                endif

                                        endif
                                endif
                        if status = 1

                                errors = errors + 1

                        else

                                sumF1 = sumF1 + f1
                                sumF2 = sumF2 + f2
                                sumF3 = sumF3 + f3
                                sumF4 = sumF4 + f4

                        endif
                endfor

                numPoints = numPoints - errors

                avF1 = sumF1 / numPoints
                avF2 = sumF2 / numPoints
                avF3 = sumF3 / numPoints
                avF4 = sumF4 / numPoints
                printline 'current_file2$''tab$''avF1''tab$''avF2''tab$''avF3''tab$''avF4''tab$''errors''tab$''numPoints'

        select Sound 'current_file2$'_ch1
        plus Pitch 'current_file2$'_ch1
        plus PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
        plus Formant 'current_file2$'_ch1
        Remove

endfor
select all
Remove
```

Figure B4: Praat script for formants F_1-F_4

```
#female voice formants

clearinfo

directory_get$ = chooseDirectory$ ("choose a directory")

Create Strings as file list...  list 'directory_get$'/*.WAV
number_of_files = Get number of strings

echo fileName'tab$'F1'tab$'F2'tab$'F3'tab$'F4'tab$'errors'tab$'points'newline$'

for x to number_of_files
      select Strings list
      Sort
          current_file$ = Get string... x
          current_file2$ = replace$ (current_file$, ".WAV", "", 0)
          Read from file...  'directory_get$'/'current_file$'

                    select Sound 'current_file2$'
                    Extract one channel... Left

                    i = 1
                    numPoints = 0
                    sumF1 = 0
                    avF1 = 0
                    sumF2 = 0
                    avF2 = 0
                    sumF3 = 0
                    avF3 = 0
                    sumF4 = 0
                    avF4 = 0
                    errors = 0

                    To Pitch (cc)...  0 150 15 no  0.03 0.6 0.01 0.7 0.3 350
                    select Sound 'current_file2$'_ch1
                    plus Pitch 'current_file2$'_ch1
                    To PointProcess (cc)
                    select Sound 'current_file2$'_ch1
                    To Formant (burg)... 0.0025 5 5500 0.025 50
                    select PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                    numPoints=Get number of points

                    for i to numPoints
                              status = 0
                              select PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
                              t = Get time from index... 'i'

                              select Formant 'current_file2$'_ch1
                              f1 = Get value at time... 1 't' Hertz Linear
                              f2 = Get value at time... 2 't' Hertz Linear
                              f3 = Get value at time... 3 't' Hertz Linear
                              f4 = Get value at time... 4 't' Hertz Linear

                    if f4 = undefined
                              status = 1
                    else
                              if f1 > 1250
                                        status = 1
                              else
                                        if f2 > 3350
                                                  status = 1
                                        else
                                                  if f3 > 4150
                                                            status = 1
                                                  else
                                                            if f4 > 5100
                    if status = 1
                              errors = errors + 1
                    else
                              sumF1 = sumF1 + f1
                              sumF2 = sumF2 + f2
                              sumF3 = sumF3 + f3
                              sumF4 = sumF4 + f4
                    endif
               endfor
               numPoints = numPoints - errors
               avF1 = sumF1 / numPoints
               avF2 = sumF2 / numPoints
               avF3 = sumF3 / numPoints
               avF4 = sumF4 / numPoints
               printline 'current_file2$''tab$''avF1''tab$''avF2''tab$''avF3''tab$''avF4''tab$''errors''tab$''numPoints'
      select Sound 'current_file2$'_ch1
      plus Pitch 'current_file2$'_ch1
      plus PointProcess 'current_file2$'_ch1_'current_file2$'_ch1
      plus Formant 'current_file2$'_ch1
      Remove

endfor
select all
Remove
```

Figure B5: Praat script for formants F1-F4

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- Extracting DNA from FTA paper blood samples; organizing and cataloging samples
- Mentor: Mark Shriver, PhD, Professor of Anthropology

Research Intern – Genetics of Addiction Lab (June 2014-July 2014)

Washington University in St. Louis **St. Louis, MO**

- Pursued an independent project exploring the influence of socio-demographic factors on a participant's consent to the broad sharing of genetic data in order to better inform recruitment strategies.
- Conducted standardized interviews and collected saliva DNA samples from participants in a large-scale genetic study of smoking and smoking related behaviors.
- Participated in weekly journal clubs and seminars by leading biomedical researchers at Washington University, St. Louis and a symposium of AMGEN scholars in Los Angeles, CA.
- Mentor: Laura Bierut, MD, Alumni Endowed Professor of Psychiatry

Research Intern – Human Paleoecology and Isotope Geochemistry Laboratory (January 2013 – May 2014)

The Pennsylvania State University **University Park, PA**

- Prepared collagen extractions from bone and dentin and ABA extractions on other organic material (charcoal, wood, etc.) for stable isotope and radiocarbon analysis of various projects in Mesoamerica, South America, and Southeastern Europe
- Worked with pipetting, centrifugation, ultrafiltration, liquid nitrogen/lyophilizing among other techniques
- Mentors: Doug Kennett, PhD, Professor of Anthropology; Brendan Culleton, PhD, Research Associate

Research Intern - Zooarchaeology Lab (September 2012-January 2013)
The Pennsylvania State University **University Park, PA**

- Sorted through hundreds of bone fragments and recording data from El Gigante cave site in Honduras
- Assisted in the organization of a comparative collection for the lab
- Mentor: Sarah McClure, PhD, Assistant Professor of Anthropology

Awards and Recognitions

From The Pennsylvania State University: Academic Excellence Scholarship (2011-Present); Dean's List (2012-Present); Lamartine Lam Hood, Jr. Endowed Scholarship (2014); Birkle Award for Student Civic Engagement (2013); Liberal Arts Enrichment Grant (2013); Schreyer Honors College Travel Grant (2013)
From Washington University in St. Louis: AMGEN Scholar in the Division of Biology and Biomedical Studies (2014)

Extracurricular Activities

Cross Country Club (2011-Present)

- Workout/Training Chair (Spring-Fall 2014); Secretary/Social Chair (Spring-Fall 2013); Captain (Fall 2012)
- Managing the workouts, the roster and social events for a club of over 200 members
- Competing at DII & DIII races and regional & national meets sponsored by NIRCA

Paterno Fellows Program Student Advisory Board (2011-Present)

- Advising the program director on issues of student events and future directions of the program
- Organizing special events reserved for Paterno Fellows including a recognition ceremony, small group meetings with incoming performers, and social events
- Spearheaded student effort for Prevent Child Abuse America's Pinwheels for Prevention at PSU which raised over $5,000 in addition to the public awareness of child abuse issues (2012-2013)

Anthropology Club (2011-Present)

- President (2013-2014), Vice-President (2012-2013)
- Engaging in club presentations ranging in cultural traditions in China and New Orleans to Mesopotamian pottery and the spread of infectious diseases.
- Providing future professional/career advice to undergrad students via graduate student, faculty, and laboratory assistant panels

Penn State Dance Marathon – THON (2011-Present)

- Fundraised to raise money for pediatric cancer treatment payments and cancer research
- Participated in family relation activities with families with children diagnosed with cancer

Language & Communication Skills

- Proficiency in French language
    - Study abroad experience in Besancon, France
    - Certification from the Centre de Linguistique Appliqué at the Université de Franche-Comté for the completion of 8 week intensive coursework in Besancon, France.
- Proficiency in public speaking

Presentations

- Dooling, S., Olfson, E., Collaborators, Bierut, L.J. Factors Influencing Whether Participants Consent to Broad Sharing of Genetic Data. Independent poster at the Washington University DBBS Summer Programs Exhibition. August 1, 2014 in St. Louis, MO.