ANIMAL BEHAVIOUR, 2005, **69**, 561–568
doi:10.1016/j.anbehav.2004.06.012

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Manipulations of fundamental and formant frequencies influence the attractiveness of human male voices

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*(Received 3 July 2003; initial acceptance 4 September 2003;
final acceptance 12 June 2004; published online 7 December 2004; MS. number: 7778R)*

In human voices, low fundamental frequency is thought to be a cue to masculinity and reproductive capability and large vocal tracts are associated with large body size of the speaker. Female preferences for males with low fundamental frequencies and large vocal tract lengths are potentially adaptive. Although sexually dimorphic characteristics of male voices have been studied, the impact of manipulations of secondary sexual characteristics on preferences for male voices has not. We manipulated fundamental frequencies and apparent vocal tract lengths of young adult male voices, both independently and simultaneously, and assessed their impact on female ratings of masculinity, size, age and attractiveness. Lowering the fundamental frequencies and/or increasing apparent vocal tract lengths of male voices increased females' ratings of the masculinity, size and age of the speaker. Peer group females preferred male voices with (1) lowered fundamental frequencies to those with raised fundamental frequencies, and (2) original frequencies to male voices with raised fundamental frequencies and decreased apparent vocal tract lengths (a combined manipulation to reflect acoustic characteristics of 16-year-old male voices). This suggests that male voices with acoustic characteristics that reflect full sexual maturity may be attractive. Although no general preference was observed for male voices with increased or decreased apparent vocal tract lengths, female preferences for male voices with increased apparent vocal tract lengths were positively related to females' own body size. This latter finding may indicate assortative preferences for acoustic cues to body size.

The source–filter model of vocal production (Chiba & Kajiyama 1941; Fant 1960) assumes that there is a source (the vocal cords) and a filter (the supralaryngeal vocal tract, hereafter referred to as vocal tract). In this model, the fundamental frequency of the voice is tied to the rate of vocal fold vibration, whereas formant frequencies are the resonant frequencies of air in the vocal tract (Titze 1994). In humans, the fundamental frequency of the voice is determined by the amount of testosterone present at the later stages of puberty, which determines laryngeal size and vocal fold length (Butler et al. 1989; Titze 1994; Harries et al. 1997, 1998). Fundamental frequencies are sexually dimorphic and steadily become lower during childhood development until puberty in both sexes (Huber et al. 1999). After this, male fundamental frequencies become lower relatively rapidly until adulthood (Huber et al. 1999). By contrast, the fundamental frequencies of females decrease at a relatively slower rate than those of males through puberty, resulting in adult fundamental frequencies that are about twice those in males (Bachorowski & Owren 1999; Huber et al. 1999). Fundamental frequencies of male red deer, *Cervus elaphus*, also decrease with physical development, such that fundamental frequency is negatively related to age and size in immature male red deer. As is the case for adult male humans, fundamental frequency of sexually mature male red deer is not related to body size (Reby & McComb 2003). Unlike in humans, however, minimum fundamental frequency and maximum vocal tract length of adult male red deer positively predicted reproductive success (Reby & McComb 2003). These findings, and those reporting that fundamental frequency of a male's voice predicts reproductive success in certain anuran species (reviewed in Hauser 1996), suggest that fundamental frequency acts as a cue to sexual maturity and reproductive capability across species. Thus, female preferences for male voices with low fundamental frequencies are potentially adaptive. Indeed, Collins (2000) showed that human male voices with lower peak frequencies, lower fundamental frequencies and smaller harmonic spacing were

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0003–3472/04/$30.00/0

more attractive. Fundamental frequency is equal to harmonic spacing because harmonics are multiples of the fundamental (Ladefoged 1996); thus the acoustic analysis in Collins (2000) included multiple measures of the same acoustic parameter. Nevertheless, each measure of fundamental frequency loaded on to the same factor in the principal components analysis. This factor correlated negatively with vocal attractiveness ratings. Therefore, the findings of Collins (2000) show that fundamental frequency predicts male vocal attractiveness.

Height of humans is sexually dimorphic and is positively related to reproductive success in males (Pawlowski et al. 2000). Vocal tract length is a correlate of size in rhesus macaques, *Macaca mulatta* (Fitch 1997), dogs, *Canis familiaris* (Riede & Fitch 1999) and humans (Fitch & Giedd 1999). In both sexes in humans, vocal tract lengths increase until full sexual maturity (Fitch & Giedd 1999). These factors suggest that female preference for male voices with longer vocal tracts could be adaptive. Vocal tract length can predict formant frequency position and dispersion (Fant 1960; Fitch & Hauser 1995). Fitch (1994) showed that, in synthesized voices, fundamental frequencies and formant frequencies independently cued speaker size, but noted that these synthetic voices may have sounded unnatural. Manipulating fundamental frequencies and apparent vocal tract lengths in real male voices, rather than synthesized voices may improve the ecological validity of such studies.

We investigated the relation between sexually dimorphic acoustic properties of the voice and vocal attractiveness by using real voices with frequency manipulations. Direct manipulations of acoustic properties allow potential mate quality cues in male voices to be evaluated without confounds from other variables (Perrett et al. 1999; Thornhill & Gangestad 1999). First, we manipulated (i.e. raised and lowered) the fundamental frequency of male voices by 20 Hz. We hypothesized that lowering the fundamental frequency would increase attractiveness, because females appear to prefer masculine aspects of male voices (Collins 2000). Second, we increased and decreased the apparent vocal tract length of male voices to change apparent speaker size. Here we hypothesized that females would prefer the voices of larger-sounding males, because male size is positively linked to reproductive success (Pawlowski et al. 2000). Finally, fundamental frequencies and apparent vocal tract lengths were manipulated simultaneously to values of 16-year-old males and 20-year-old males (Huber et al. 1999). Because many studies have grouped all adult males into one fundamental frequency category and because of the relatively subtle changes that happen to the male voice after puberty (Childers & Wu 1991; Huber et al. 1999), we chose to explore the difference between mature and immature male voices. Because Buss (1989) reported female preferences for males older than themselves, we hypothesized that women would prefer the older-sounding male voices.

Collins (2000) suggested that because there is general agreement among raters, it is important to determine overall preferences. Recently, individual differences in preference strength have been investigated. Pawlowski (2003) has shown that a female's own height predicts her preference for the relative height of opposite-sex partners. We thus also investigated whether a female rater's height and weight predict the strength of her preference for male voices manipulated to have acoustic properties that indicate increased or decreased body size.

METHODS

Participants included 10 males from Rutgers University aged 20–22 years ($\overline{X} \pm SD = 20.4 \pm 0.84$ years) and 89 females aged 17–24 years (19.89 ± 1.62 years) from the University of St Andrews (77 females participated in the attractiveness ratings and 12 randomly selected females participated in the stimulus calibration ratings). Both the University of St Andrews and Rutgers University ethics committees approved the protocol for this study. Participants gave informed consent and were paid £4 or $10, respectively, for participating. Male participants were Caucasian, and female participants were of mixed ethnicities ($N = 86$ Caucasian and 3 non-Caucasian). Female participants' height (cm) and weight (kg) were measured with metric tape and a metric digital scale. Sexual orientation was self-reported.

We recorded 10 male voices speaking the common English vowels A E I O and U with a northeastern American accent (mean duration $\pm$ SD $= 0.64 \pm 0.14$ s), using a Rode NT 2 cardioid microphone (http://www.rode.com). The vowel U was later excluded because in six participants it was distorted by offset noise, because it was the final vowel spoken. The vocal samples were encoded with Digidesign's ProTools software (Avid Technology, Inc., Digidesign, Daly City, CA, U.S.A.) at CD quality (18 bit external audio-digital conversion, 16 bit quantization and a 41.1 kHz sampling rate). All recordings were resampled to 11.025 kHz sampling rate with a low-pass antialiasing filter. Resampling to 11.025 kHz creates a Nyquist frequency of 5.5 kHz, which is roughly the maximum formant frequency for adult human speech; hence resampling reduces extraneous information in the sound file, not produced by the voice (Ladefoged 1996).

Acoustic Measurements

All acoustic measurements and manipulations were made with Praat Software version 4.0.29 (P. Boersma & D. Weenink, www.praat.org). Fundamental frequency was measured by a noise-resistant autocorrelation method, between 60 and 300 Hz with a Hanning window length of 0.05 s. The algorithm measures a fundamental frequency for each voiced window in the signal. The values presented here are the mean $\pm$ SD fundamental frequency across the entire vowel to account for variation in the fundamental frequency. The mean fundamental frequency values for each vowel were subsequently averaged across speakers for each manipulation.

We used multiple vowels to calculate mean formant frequency values; some of these vowels were diphthongs and contained formant transitions. We chose this technique because it should adequately represent the average size and shape of the vocal tract of the speakers for each manipulation. To calculate formant frequencies we used the Burg linear predictive coding (LPC) algorithm (www.praat.org) with a time step of 0.01 s, a maximum formant value of 5.5 kHz, a window length of 0.025 s, and a pre-emphasis from 50 Hz. Prediction points were overlaid on spectrograms at intervals representing the mean value for each window length, and the input parameters (maximum formant, number of formants to retrieve, window length and dynamic range) were modified. Predicted formants were then recalculated to obtain the best-fitting prediction. The formant frequency algorithm measures formant frequencies for each window in the signal. Formant values presented here (mean ± SD) were calculated across the entire vowel and subsequently averaged across vowels for each voice, and then again across speakers for each manipulation.

Formant dispersion, an estimator of vocal tract length, was calculated by finding the average distance between successive formants (Fitch 1997). Smaller dispersion indicates longer vocal tracts. Because each manipulation was applied to a windowed signal, each window length will have been manipulated relatively equally, and the mean values (±SD) of the fundamental and formant frequencies presented here thus record the characteristics of the vocal manipulations.

Acoustic Manipulations

The fundamental frequencies (Fig. 1a, b) of five male voices were lowered and raised by 20 Hz with the PSOLA method (Pitch-Synchronous Overlap and Add; Charpentier & Moulines 1989; P. Boersma & D. Weenink, www.praat.org). This method allows for a fundamental frequency (and corresponding harmonics) manipulation, while preserving apparent vocal tract length (formant dispersion) and vice versa. Although individual formants varied, the difference in formant dispersion between voices with the fundamental frequency manipulated was less than 1%. We created 10 novel voices (five increased fundamentals, five decreased fundamentals), each speaking a series of vowels, from the five original voices.

We manipulated apparent vocal tract lengths by raising or lowering the entire sound spectrum (while preserving duration) to the appropriate levels such that the formant dispersion of the manipulated voices would be about 95 or 105% of the original formant dispersion. Then the fundamental frequency was manipulated back to the original value using the PSOLA method (www.praat.org; Fig. 1c, d). The same original five voices used in the fundamental frequency manipulation to create 10 novel voices (five with lengthened, five with shortened vocal tract lengths). The difference in fundamental frequency in these voices, intended to be manipulated in formant dispersion only, was less than 1 Hz and the mean difference in formant dispersion between voices intended to be manipulated in fundamental frequency only was 6 Hz, both of which are below the just noticeable difference for complex wave forms such as the vowels presented here (Ladefoged 1996). Differences between individual formant values between manipulations are likely to be negligible perceptually and may result from measurement error stemming from the parameters used in the Burg LPC analysis.

A third 'combined' manipulation transformed the fundamental (harmonic) and formant frequencies simultaneously for five separate voices (aged 20–22 years) speaking the same series of vowels (Fig. 1e, f). Five new voices were modified so that familiarity with the voices from previous trials would not influence ratings. We used manipulation to create voices with fundamental and formant frequencies of the average 16-year-old male as described by Huber et al. (1999) (see Table 1 for target frequencies). To create voices with 16-year-old characteristics, we combined the previous two manipulations. Simultaneously, the fundamental frequency was raised 20 Hz and the apparent vocal tract length decreased by 5%. To create voices with acoustic properties of 20-year-olds, we changed the manipulated series of vowels (from the 16-year-old transform) back to their original frequencies. This manipulation was done to avoid the possibility that the 20-year-old voices would be more attractive because they were not manipulated.

The amplitude of all vocal stimuli was normalized to the root mean square at −10 dB before playback. Transformed values are given in Table 1. Examples of voice transforms can be heard at http://www.perceptionlab.com/manipulated_voices/manipulated_voices.html.

Procedure

All series of vowels were presented in the order A, E, I, O at a constant interval (0.5 s). The order in which the vocal stimuli were played was randomized. Participants listened to vocal samples via Sennheiser HD280-Pro headphones with a flat frequency response from 20 Hz to 20 kHz (the range of human hearing; http://www.sennheiser.com).

Masculinity, Size and Age Estimation

In one experimental block, 12 female participants listened to each of the 30 male voices each speaking the series of vowels. This block was run as a stimulus calibration, separate from attractiveness ratings. Each female assessed each voice, with ad libitum repetitions of individual voices, in a random order. Each participant recorded apparent masculinity on a scale from 1 to 7 (1 = very feminine, 4 = neutral, 7 = very masculine), size (1 = very small, 4 = medium, 7 = very large) and age (within the range 13–26 years) of the speaker, simultaneously, in each trial.

Attractiveness Judgements

Three separate experimental blocks were created for attractiveness ratings of the three types of stimuli. Each block contained 10 novel vocal samples created from five original male voices. A computer program presented both the blocks and stimuli within blocks, in a random order. Sixty-eight females listened to and assessed speaker attractiveness. Voices were presented one at a time, and

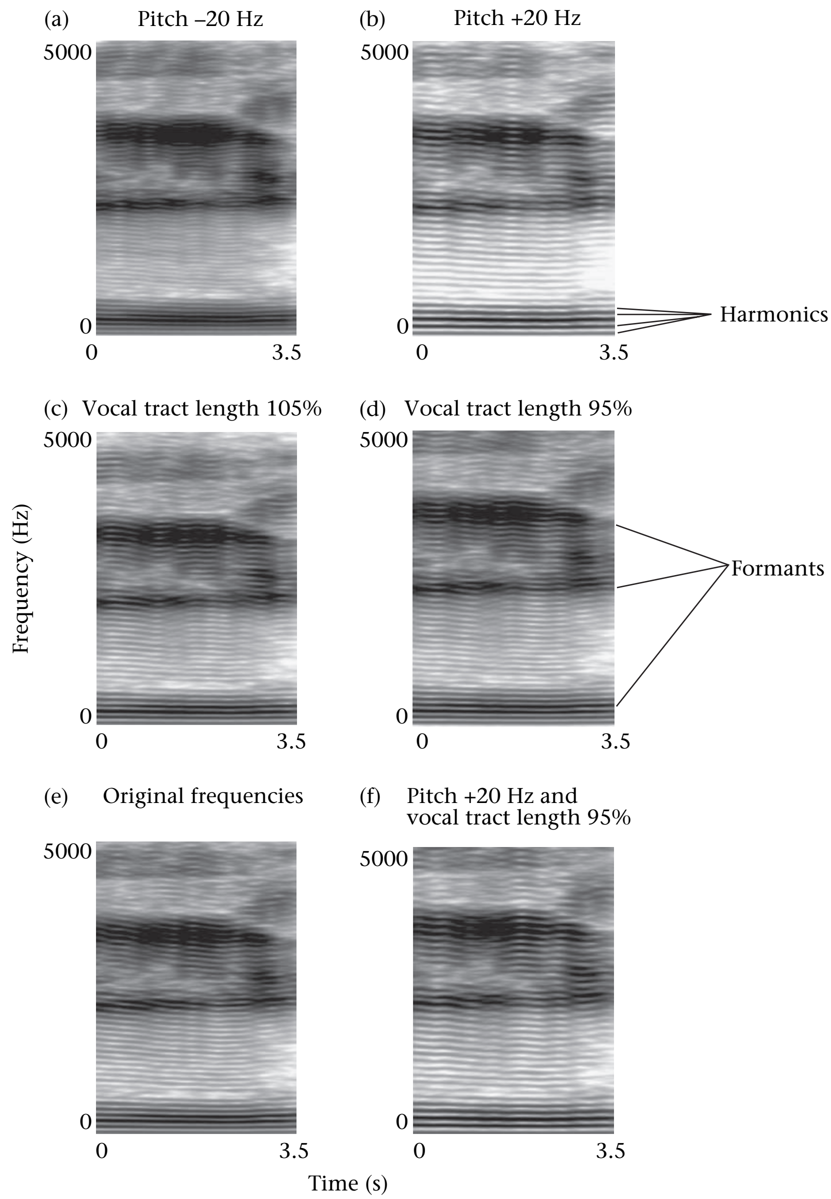

Figure 1. Spectrograms of the vowel E before and after each manipulation. In (a) and (b) the fundamental frequencies (pitch) of five male voices were lowered and raised by 20 Hz, respectively. In (c) and (d) the apparent vocal tract lengths were modified by 105% and 95%, respectively. (e) Original frequencies of voices of 20–22-year-old males; (f) these voices transformed to resemble those of 16-year-old males by raising the fundamental frequencies by 20 Hz and decreasing the apparent vocal tract length by 5%. Shading represents amplitude (louder is darker). The fundamental frequency manipulation can be seen from the change in the position of the first harmonic (the fundamental frequency) and the harmonic spacing (the spacing of the horizontal striations in the plot). The vocal tract manipulation is shown by the change in formant spacing (the spacing of the four dark broad bands of acoustic energy in the plot).

participants recorded assessments on the screen on a scale from 1 to 7 (1 = very unattractive, 4 = neutral, 7 = very attractive). In each experimental block, participants were allowed to play each voice (spoken series of vowels) with ad libitum repetitions, before assigning an attractiveness score, and proceeding to the next trial.

Acoustic Analysis

The fundamental frequencies after acoustic manipulations were considered to be within the male vocal range because the mean adult male fundamental frequency ± SD is 124.6 ± 20.5 Hz. The mean adult female fundamental frequency ± SD is about 225 ± 27.4 Hz (Childers & Wu 1991). The total transformed voice sample reported here had fundamental frequencies with a mean ± SD of 116 ± 6.7 Hz (Table 1).

Statistical Analysis

We excluded participants from analysis if they reported hearing problems ($N = 7$), and/or nonheterosexuality ($N = 3$, one reported both), resulting in a final number of 68 female raters. All analyses used two-tailed probability

Table 1. Mean ± SD fundamental and formant frequencies (Hz) and formant dispersion

	F0	F1	F2	F3	F4	Formant dispersion
Original voices (N=10)	111±7	488±95	1723±169	2711±106	3504±141	1005
Lowered fundamental	96±6	498±107	1754±184	2735±136	3627±162	1043
Raised fundamental	136±6	493±81	1742±164	2726±113	3640±138	1049
Vocal tract lengthened	116±6	475±99	1681±190	2624±139	3488±168	1004
Vocal tract shortened	116±7	504±91	1829±171	2843±118	3817±167	1105
Age reduced to 16 years	125±8	505±82	1777±146	2800±78	3482±139	992
Age restored (original 20 years)	105±7	497±100	1708±149	2716±93	3419±147	974
16-Year-old target*	120	670	1273	2442	N/A	886
20-Year-old target*	106	666	1232	2585	N/A	959

F0: Fundamental frequency (Hz); F_n: formant (n) (Hz); formant dispersion (Hz) = ((F4 − F3) + (F3 − F2) + (F2 − F1))/3. Each mean value was calculated from the mean value for each vowel, averaged across vowels, for each voice (N = 5, except where noted). Mean values were then calculated for each manipulation type. The formant dispersion values of the combined manipulation (16-year-old and 20-year-old voices) are smaller (<1000 Hz) than those of the other manipulations (>1000 Hz) because they originated from five different speakers to the other two manipulations, with apparently longer starting vocal tract lengths.
*Target values from Huber et al. (1999). Formant dispersion calculated as (F3 − F2) + (F2 − F1)/2.

estimates. Although not every rater used the full scale each time, the extremes of the scales were used by individuals such that certain feminized voices received ratings of 1 (very feminine or very unattractive, etc.) and certain masculinized voices received ratings of 7 (very masculine or very attractive, etc.). Given that we compared mean ratings for each manipulation across speakers rather than ratings for each individual speaker, we also investigated the distribution of the ratings for each manipulation. The average ratings for each manipulation were all normally distributed: all one-sample Kolmogorov–Smirnov P values were greater than 0.05. All stimuli calibration ratings (ratings of masculinity, size and age) for each voice were also normally distributed with one-sample Kolmogorov–Smirnov P values greater than 0.05, as were mean values per manipulation.

Agreement Between Raters

Agreement between raters, estimated for raw scores using Cronbach's Alpha, was $\alpha = 0.93$ for masculinity ratings, $\alpha = 0.85$ for size ratings, $\alpha = 0.90$ for age ratings, and $\alpha = 0.95$ for attractiveness ratings. Since interrater reliability was very high ($\alpha > 0.8$ in all cases) we consider that in general females agree on assessments (Bohrnstedt 1970).

Paired Comparisons

We calculated mean scores for each female participant by averaging ratings of each voice, for each type of acoustic manipulation. The analysis compared preferences across listeners. Thus, the degrees of freedom reported in the t tests reflect female participant sample size, rather than number of male voices heard.

Individual Differences and Preference Scores

For each female listener and acoustic manipulation, we created preference scores by subtracting the mean of five attractiveness ratings of the series of vowels with one direction of manipulation from the mean of the five ratings of the opposite direction of manipulation (e.g. attractiveness of lowered fundamental frequencies minus attractiveness of raised fundamental frequencies).

RESULTS

Masculinity, Size and Age

We used paired-sample t tests of mean ratings of masculinity, size and age to test the effect that the manipulations had on female listeners' assessments. These tests compared a mean rating from each female for each vocal group. Voices with increased apparent vocal tract lengths were rated larger, more masculine and older than voices with decreased apparent vocal tract lengths (Table 2). Voices with lowered fundamental frequencies were rated larger, more masculine and older than voices with raised fundamental frequencies. Voices with the combined control manipulation of reconstructed original fundamental frequencies and vocal tract lengths were rated larger, more masculine and older than voices with the combined manipulation of raised fundamental frequencies and increased apparent vocal tract lengths. The mean perceived age of voices with original frequencies ± SD was 22.9 ± 1.3 years and the mean perceived age of voices with raised fundamental frequencies and shortened apparent vocal tract lengths ± SD was 20.0 ± 2.7 years.

Attractiveness

Voices with lowered fundamental frequencies were preferred to voices with raised fundamental frequencies (Table 2). Attractiveness assessments of voices with increased apparent vocal tract lengths showed no significant difference from voices with decreased apparent vocal tract lengths (Table 2). Voices with combined fundamental frequencies raised and apparent vocal tract lengths decreased were rated less attractive than voices with original fundamental frequencies and vocal tract length characteristics (Table 2). Although the number of times voices were played was not recorded, total listening time for each voice was. Correlational analyses showed that time spent on each

Table 2. Paired-sample *t* test results for masculinity, size and age

Assessment	Manipulation	Difference ($\overline{X}\pm$SD)	*df*	*t*	*P*
Size	Vocal tract length	0.93±0.73	11	4.5	0.001
Size	Fundamental frequency	0.80±1.06	11	2.6	0.024
Size	Combined	1.28±0.78	11	5.7	0.001
Masculinity	Vocal tract length	1.18±0.85	11	4.8	0.001
Masculinity	Fundamental frequency	1.83±1.12	11	5.7	0.0001
Masculinity	Combined	1.92±0.85	11	7.8	<0.001
Age	Vocal tract length	2.25±1.40	11	5.7	0.0001
Age	Fundamental frequency	2.90±1.59	11	6.3	0.0001
Age	Combined	2.93±2.19	11	4.6	0.001
Attractiveness	Vocal tract length	0.1±0.94	66	0.6	0.352
Attractiveness	Fundamental frequency	0.7±0.95	66	6.4	<0.001
Attractiveness	Combined	0.38±0.80	66	3.9	0.0002

voice had no systematic effect on attractiveness ratings (only two speakers' ratings correlated significantly with the time spent listening, and these correlations were in opposite directions). We also tested these effects while excluding non-Caucasians and there was no difference in the results. Therefore, group was included in these analyses.

Individual Differences and Preference Scores

Female height and weight were positively correlated with each other (Spearman correlation: $r_S = 0.419$, $N = 68$, $P < 0.001$). Height and weight of female participants also correlated positively with preference scores for voices with manipulated apparent vocal tract lengths (height: $r_S = 0.241$, $N = 68$, $P = 0.048$; weight: $r_S = 0.291$, $N = 68$, $P = 0.016$) but not with preference scores for voices with only manipulated fundamental frequencies (height: $r_S = 0.09$, $N = 68$,$P = 0.47$; weight: $r_S = 0.16$, $N = 68$, $P = 0.20$) or preference scores for voices with the combined manipulation (height: $r_S = 0.004$, $N = 68$, $P = 0.97$; weight: $r_S = 0.02$, $N = 68$, $P = 0.88$). Thus, larger females preferred voices of males manipulated to increase apparent size. These results were also analysed excluding three non-Caucasians. The correlation between height and preference for formant-manipulated voices became a nonsignificant trend, and the correlation between weight and preference for formant-manipulated voices became stronger. Age still did not correlate with any preferences. Since these effects were not systematic, non-Caucasians were included in the analysis.

There was no evidence of assortment in preferences of apparent speaker age. Indeed, listeners' own ages did not correlate significantly with preference scores for any manipulation: fundamental frequency decrease (Spearman correlation: $r_S = 0.11$, $N = 68$, $P = 0.35$), apparent vocal tract length increase ($r_S = 0.10$, $N = 68$, $P = 0.40$) or combined manipulation simulating a change in speaker age ($r_S = 0.04$, $N = 68$, $P = 0.74$).

DISCUSSION

Fundamental Frequency

The manipulation of fundamental frequency revealed a female preference for male voices with lowered fundamental frequencies. This relation is in agreement with Collins (2000) who found that fundamental frequency is a correlate of male vocal attractiveness. The present study provides explicit evidence for the relation between fundamental frequencies and attractiveness of male voices because the selective manipulation allowed other potential acoustic confounds (e.g. formant dispersion) to be held relatively constant.

This preference for low fundamental frequency suggests a preference for high testosterone and high masculinity. As masculine traits have been linked to aspects of male quality (e.g. immunocompetence, health, dominance; Folstad & Karter 1992; Rhodes et al. 2000, 2003; Johnston et al. 2001), the preference for males with low fundamental frequencies is potentially adaptive. In addition, this finding suggests a female preference for male voices that make the speaker sound larger, although fundamental frequency is not a valid cue for size of adult males.

Size Preference

We hypothesized that females would prefer the voices of larger-sounding males because male size is positively linked to reproductive success (Pawlowski et al. 2000) but our results offered no support for this hypothesis. The acoustic manipulation designed to increase the apparent vocal tract length produced a significant increase in the perception of speaker size. This manipulation, however, did not significantly affect the overall attractiveness ratings of the voices. Although the modest apparent vocal tract length manipulation was strong enough to drive other attributions, perhaps a larger difference in vocal tract length is needed to affect overall attractiveness ratings.

Acoustic manipulation of apparent vocal tract lengths did affect vocal attractiveness ratings at a more subtle level. Listeners' weight and height correlated positively with preference for voices with increased apparent vocal tract lengths. Taller and heavier females preferred male voices with increased apparent vocal tract lengths. Although our results are not directly comparable with those of Pawlowski (2003), both studies show that female height influences preferences for male body size, as formant dispersion is related to height and weight (Fitch & Giedd 1999).

Age Preference

The combined manipulation of fundamental frequency and apparent vocal tract length was designed to decrease the apparent age of speakers. The acoustic manipulation produced the intended effect on perceived speaker age and in addition it altered speaker attractiveness. Peer-aged females found voices transformed to sound relatively younger less attractive. This female preference for male voices with the combined manipulation indicates that age, or perhaps sexual maturity, is an important factor in female mating preferences. This finding is in accordance with Buss (1989) who showed that, in general, females prefer males older than themselves. The preference for voices with increased apparent vocal tract lengths and lowered fundamental frequencies could potentially be driven solely by lowering the fundamental frequency, as increasing only apparent vocal tract length had no overall effect on attractiveness. It is relevant in this context that Reby & McComb (2003) found that fundamental frequency and vocal tract length positively predicted reproductive success in red deer.

Unlike the assortative preferences for apparent speaker size, there was no relation between age of the listener and the age preference score: older women did not show a stronger preference for older-sounding male voices.

Acoustic Transforms and Speaker Attributions

Vocal tract length is related to body size in rhesus macaques (Fitch 1997), dogs (Riede & Fitch 1999), and humans (Fitch & Giedd 1999). The finding that males with increased apparent vocal tract lengths were rated as larger replicates work on synthetic voices by Fitch (1994). This result may provide further evidence that formant frequency dispersion and formant frequency height act as valid cues to size (Fitch 1994; Fitch & Hauser 1995; Fitch & Giedd 1999).

Fundamental frequencies are independent of height and weight in adult humans (Lass & Brown 1978; Cohen et al. 1980; Künzel 1989; van Dommelen 1993). In the current study, however, females rated male voices with lowered fundamental frequencies as larger. For adult male voices, fundamental frequency thus appears to be used inappropriately by listeners as a cue to speaker size, as others have observed (Fitch 1994; Fitch & Hauser 1995; Fitch & Giedd 1999; Collins 2000). As noted by Fitch (1994), the perception that fundamental frequency relates to size may arise because fundamental frequency changes steadily with growth until puberty. In addition, height and fundamental frequency are sexually dimorphic (men are taller and have lower-frequency voices than women). Thus, fundamental frequency does carry information about likely sex and stage of development and hence the size of an individual. None the less, listeners may overgeneralize the relation between fundamental frequency and size when judging adult male voices.

Females rated males with increased apparent vocal tract lengths as more masculine. Because body size is sexually dimorphic, apparent vocal tract lengths should act as a cue to male–female differences and may hence be a valid cue to masculinity. Fundamental frequency and vocal tract length manipulations were both components of the combined manipulation, and naturally change with age. This may explain why independent manipulations of fundamental frequency and vocal tract length both had an effect on perceived speaker age.

The combined manipulation intended to simulate a change in speaker age did produce its intended effects: voices with raised fundamental frequencies and shortened vocal tract lengths were judged significantly younger than voices with original frequencies. The age assessments, however, did not map on to the intended age of the manipulation (16 years old). This may reflect the fact that the formant dispersion values from Huber et al. (1999) come from one monopthong vowel and here were applied to four different diphthong vowels and may have produced older ages than previously estimated.

In summary, this is the first study to manipulate sexually dimorphic acoustic parameters of natural voices and measure their impact on male vocal attractiveness. While it is possible that there are other contributing factors to voice attractiveness, our methods allowed us to isolate independent contributions of two acoustic cues to attractiveness (fundamental frequency and vocal tract length). Thus, even in the presence of other potential correlates of vocal attractiveness, natural human male voices manipulated to have lowered fundamental frequencies were rated as more attractive than voices with raised fundamental frequencies. Male voices with increased apparent vocal tract lengths were more attractive only to taller and heavier females. Male voices manipulated to sound younger (by raising fundamental frequency and decreasing apparent vocal tract length) were perceived as less attractive than older-sounding male voices. This study lends support to the hypothesis that testosterone-dependent secondary sexual characteristics, such as pitch of voice, cue mate value.

Acknowledgments

We thank Jacob, Paul and Nancy Feinberg for help recording voices; Lesley Ferrier for organizing testing; all participants for their time; Lynda G. Boothroyd, R. Elisabeth Cornwell, Laura Johnson and Carolyn Cheetham for aid in data collection; Michael J. Owren for help with acoustical analysis; Amy S. Jacobson, Janielle Tortorice, H. Deiter Steklis, Lee Cronk and Robert L. Trivers for their contributions to pilot studies; Michael W. Oram, Paul Hibbard, Karen McComb, David Reby, W. Tecumseh Fitch and two anonymous referees for their insightful comments on the manuscript; and Anne Perrett and Angela K. Turner for editing.

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