Behav Ecol Sociobiol
DOI 10.1007/s00265-010-0981-5

ORIGINAL PAPER

Vocal masculinity is a robust dominance signal in men

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Received: 20 November 2009 / Revised: 30 April 2010 / Accepted: 3 May 2010

Abstract Dominance assessment is important in mating competition across a variety of species, but little is known about how individuals' own quality affects their assessment of potential rivals. We conducted two studies to test whether men's own dominance affects their attentiveness to a putative dominance signal, vocal masculinity, when assessing competitors. Study I examined dominance ratings made by men in relation to their self-rated physical dominance. Study II examined dominance ratings made by men in relation to objective measures of their physical dominance, including size, strength, testosterone, and physical aggressiveness. Vocal masculinity strongly affected dominance ratings, but a man's own dominance did not alter his attention to vocal masculinity when assessing dominance. However, men who rated themselves high on physical dominance rated the voices of other men lower on dominance and reported more sex partners (study I). Men with intermediate testosterone concentrations rated the voices of other men lower on dominance (study II). These results confirm the effect of vocal masculinity on dominance perceptions, provide further evidence that dominance is relevant to mating success, and shed new light on how men assess the dominance of rivals and potential allies. Our results suggest that attention to dominance signals may depend less on the observer's own dominance in species with coalitional aggression, where individuals must assess others not only in relation to themselves but also in relation to each other. Among men, the effect of a deep, masculine voice on perceptions of dominance appears to be robust and unmediated by the formidability of the listener.

Keywords Dominance · Formant frequency · Fundamental frequency · Mating success · Sexual selection · Voice pitch

Introduction

Dominance and attractiveness have appropriately been the focus of much research on sexual selection in men, as these are the primary means by which males win mates across species (Darwin 1871; Andersson 1994). Observers' perceptions of men's dominance and attractiveness have been shown to be affected by facial and vocal masculinity (e.g., Penton-Voak and Perrett 2000; Feinberg et al. 2005; DeBruine et al. 2006; Puts et al. 2006). Despite considerable agreement in these perceptions, there is also substantial variation among ratings made by different observers.

Women's preferences for masculinity are affected by multiple factors, including but not limited to menstrual cycle phase (Grammer 1993; Frost 1994; Penton-Voak et al. 1999; Penton-Voak and Perrett 2000; Johnston et al. 2001; Gangestad et al. 2004; Puts 2005; Feinberg et al. 2006; Puts 2006; Little et al. 2007a), interest in uncommitted sex (Provost et al. 2006), involvement in romantic relationships (Little et al. 2007b), and exposure to attractive women's faces (Little et al. 2002). Symons (1995) wrote that "beauty is in the adaptations of the beholder." The evidence indeed suggests that women's mate preferences track fitness-relevant features of the women themselves and their contexts. For example, increased masculinity preferences near ovulation and in short-term, sexual mating contexts appear to function in recruiting genetic benefits for offspring (Gangestad and Thornhill 2008).

Communicated by T. Czeschlik

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One might similarly expect perceptions of same-sex dominance to reflect the adaptations of the beholder. Physical dominance is a description of the regularities of winning or losing fights, those with higher physical dominance win more fights, and dominant individuals are given priority access to mates and resources (Archer 1988). Dominance displays gain an individual access to scarce resources, including mates, while minimizing the energetic costs and injury risks of fighting (Wilson 1975; Archer 1988). In male–male competition, assessment of other males' dominance displays is important in making decisions about when to fight or submit in conflict situations (Sell et al. 2009).

Among humans, dominance has been associated with mating and reproductive success in modern cultures (e.g., Chagnon 1988; Perusse 1993) and is likely to have been important to fitness among ancestral men. Burriss and Little (2006) found that men rated other men's faces as more dominant when their female partner was not using oral contraceptives and in the high conception risk phase of her ovulatory cycle. This suggests that elevated estimation of rivals' threat potential may be a counterstrategy to prevent female infidelity when the risk of cuckoldry is greatest (Burriss and Little 2006).

Despite the salience of dominance interactions, no studies of which we are aware have addressed the causes of variation among men in their attentiveness to dominance indicators. However, in the same way that women vary in the degree to which a man's masculinity affects their judgments of his attractiveness, men vary in the degree to which a man's masculinity affects their judgments of his dominance. One might expect that dominant men could afford to be less attentive to dominance cues and thus that the relationship between own dominance and attentiveness to dominance signals would be negatively linear. Among talapoin monkeys, for example, dominant males pay less attention to other males than do subordinate males (Keverne et al. 1978). In contrast, among *Polistes dominulus* wasps, an individual's dominance curvilinearly predicts deference to rivals (Tibbetts et al. 2009). Using facial patterns that signal fighting ability, *P. dominulus* choose the apparently weaker of two rivals only when the rivals' apparent fighting ability is close to that of the chooser. If the rivals appear much stronger or much weaker, the chooser exhibits no preference (Tibbetts et al. 2009). Perhaps the relationship between a man's dominance and his attentiveness to dominance signals is similarly curvilinear. Alternatively, dominant men may be more attentive to dominance signals, as they may have achieved their status partly due to elevated attention to dominance and their own status. In short, there are multiple plausible relationships between men's dominance and their attention to dominance signals, highlighting the need for research in this area.

The human voice constitutes an excellent trait for examining between-subject variation in dominance attributions. The human voice is highly sexually dimorphic. Pitch, the most salient feature of human voice, is largely influenced by fundamental frequency (F_0) (Titze 2000; Howard and Murphy 2008), which is approximately half as high in men as in women (Titze 2000). Formant frequencies, the peaks in a sound spectrum, are also lower and more closely spaced in men compared to women (Rendall et al. 2005). The spacing between formant frequencies has been termed formant dispersion (D_f) (Fitch and Giedd 1999). At puberty, vocal sex differences emerge when increased testosterone levels cause males' larynges to descend and their vocal folds to grow faster than overall body growth (Fitch and Giedd 1999; Lee et al. 1999).

Contest competition was likely an important means by which ancestral men competed for mates (Puts 2010), and several lines of evidence suggest that vocal masculinity in particular functioned as a dominance signal in this context (Ohala 1983, 1984; Tusing and Dillard 2000; Puts et al. 2006, 2007). First, male voice recordings experimentally lowered (masculinized) in F_0 and D_f are rated as more dominant by men (Feinberg et al. 2006; Puts et al. 2006, 2007; Jones et al. 2010) and older, larger, and more dominant by women (Feinberg et al. 2005; Feinberg et al. 2006) than the same voices with these acoustic parameters raised. Vocal masculinity more strongly affects men's perceptions of a man's dominance than it affects women's perceptions of his attractiveness (Feinberg et al. 2006; Puts et al. 2006; Jones et al. 2010). Second, vocalization pitch modulation affects and reflects dominance and submissiveness across animal species (Morton 1977), including humans (Puts et al. 2006). Men who perceived themselves to be physically dominant to their competitor lowered their voice pitch when addressing him, whereas men who believed they were less dominant raised their pitch (Puts et al. 2006). Finally, men's mating success is more strongly associated with men's dominance ratings of their voices than with women's attractiveness ratings, suggesting intrasexual selection for vocal masculinity (Puts et al. 2007).

In the present paper, we explored whether men's attentiveness to vocal masculinity during dominance assessment would be influenced by their own dominance. We conducted two studies to illuminate the sources of variation between men in patterns of attributing dominance. In study 1, we utilized unpublished data collected in a previous study (Puts et al. 2006) to examine whether self-rated physical dominance was related to men's patterns of rating other men's dominance. In study 2, we explored relationships between patterns of dominance rating and more objective measures of physical formidability and threat, including size, strength, and testosterone levels, as well as self-assessed physical aggressiveness. We predicted that (1) more masculine voices would be perceived as more dominant—specifically that F_0 and D_f would independently affect perceptions of dominance among men, replicating the finding of Puts et al. (2007), (2) more dominant men would report higher mating success, and (3) men's own dominance would affect their attentiveness to vocal masculinity when assessing dominance, although specific predictions regarding the direction (e.g., negative vs. positive) and shape (e.g., linear vs. quadratic) of this relationship could not be made given the multiplicity of plausible alternatives.

Study I

Materials and methods

Participants One hundred ninety-eight native English-speaking self-identified heterosexual undergraduate men took part in this University of Pittsburgh IRB-approved study. One hundred eleven men (mean age=18.9, range=18-24, SD=1.2) provided voice recordings used as stimuli in the present study. Eighty-seven men (mean age=19.95, range=18–28, SD=2.1) participated as raters. Raters attended one of 11 rating sessions (approximately eight raters per session) held in classrooms with audio equipment on which stimulus sets were played.

Procedures for generating voice recordings Each participant providing voice recordings was seated in a soundproof recording room, approximately 2.5×3 m, with a computer monitor and headphone/headset microphone. The participant was informed that he would be competing against a man in another room for a lunch date with a woman in a third room, following a protocol similar to that of Simpson et al. (1999). Unbeknownst to the participant, the competitor and potential female date were confederates who had previously been audio and audio/video recorded, respectively. Recordings of both the competitor and the potential female date were spliced into a single audio/video file that the experimenter could start and stop according to the participant's response length. Participants were recorded at several times, including while they informed their competitor why other men might respect or admire them. After the dating game scenario, participants filled out a questionnaire targeting age, self-rated dominance, dominance of competitor, number of sex partners in the past year, and several variables not used in the present study. Self-rated physical dominance and competitor's physical dominance were measured by agreement on six-point scales with the statement "If [I/this man] got into a fistfight with an average male undergraduate student, [I/this man] would probably win." Number of sex partners was assessed by having the participant enter on the questionnaire the number of different individuals with whom he had engaged in sexual intercourse over the past year. The number of past-year sexual partners (vs. lifetime partners) was chosen because it is less confounded by age and represents an interval over which participants' recollections were expected to be accurate and physical dominance, a hypothetical correlate, would likely have been relatively stable (see also Faurie et al. 2004). For further information, see Puts et al. (2006).

Recordings of the male participants speaking to the competitor were used as stimuli. The average fundamental frequency (F_0) for the stimuli was measured using Praat voice analysis software (mean F_0=112.7 Hz, range=82.9–158.9 Hz). Following the programmers' recommendations for measuring men's voices, the pitch ceiling was set to 300 Hz, and the pitch floor was set to 75 Hz. Because male deference to vocal masculinity was later measured as a function of the recordings' F_0, it was desirable to increase the total F_0 range available for ratings, thus increasing the potential for F_0 to affect ratings. The voices were therefore either raised or lowered by one semitone, which did not affect speed, using the acoustic software program Cool-Edit2000. Manipulations were slightly more than twice the just noticeable difference (JND), defined as the smallest increment for which the average listener could perceive a difference 50% of the time. After manipulation, the F_0 recording range was increased to 78.2–168.4 Hz. Formant structure was also shifted, but these shifts (approximately 8% of original formant values) were in the same direction as F_0, producing either a lower, more masculine voice or a higher, more feminine voice (see Puts et al. 2006 for further details).

One masculinized recording was not produced due to experimenter error. Hence, 332 recordings were produced, comprising 111 raised, 111 unmodified, and 110 lowered. Eleven stimulus sets were compiled, each containing approximately 30 recordings. Each stimulus set was designed to include no more than one version of a single male's vocal recording and nearly equal numbers of raised, lowered, and unmodified recordings. Manipulations produced obvious differences in vocal masculinity between otherwise identical recordings, but all recordings sounded natural, and no rater reported any suspicion of recordings having been altered.

Rating procedures On arrival in a classroom used for testing, raters received a packet containing rating sheets and a demographic questionnaire. The experimenter instructed raters that obtaining independent ratings was important, and not to pay attention to others or to react visibly or audibly to the stimulus set recordings. The experimenter then played a stimulus CD.

First on the CD was a description of what the raters would hear: recordings of men describing themselves to a competitor. Second were directions to rate each of the 30 male vocal recordings for physical dominance, which was described as "If this man got into a fistfight with an average male undergraduate student, this man would probably win." Ratings were made on a visual analog scale with 100 unlabeled tick marks anchored at "definitely win" and "definitely lose." Third on the CD were five sample recordings to familiarize the raters with the stimulus sets. Fourth was the stimulus set, containing approximately 30 raised, lowered, and unmanipulated voice recordings. Each recording was separated by 10 s of silence for rating. Fifth were directions to fill out a questionnaire at the end of the rating pack. A 25-year-old woman spoke all instructions on the CD in a pleasant, professional tone.

The questionnaire targeted age, number of sex partners in the past year, self-rated dominance, and several variables not used in the present study. Self-rated physical dominance assessed level of agreement with the statement, "If I got into a fistfight with an average male undergraduate student, I would probably win," using a visual analog scale like that used in rating recordings.

Data treatment Because it is highly conspicuous, strongly sexually dimorphic, and androgen-dependent, fundamental frequency (F_0) was used as a measure of vocal masculinity. The magnitude and strength of each rater's attentiveness to vocal masculinity were then computed, as was his mean physical dominance rating and his relative physical dominance. Attentiveness magnitude, measured by the slope of dominance ratings regressed on F_0, is the degree to which a change in F_0 and its verbal and acoustic correlates, including formant structure, predict a change in a man's dominance attributions. Attentiveness strength, measured by the correlation between F_0 and a man's dominance ratings, is the extent to which F_0 and its verbal and acoustic correlates accurately predict a man's dominance attributions. For clarity, the signs of attentiveness magnitude and strength were reversed, so that attentiveness to more masculine voices was positive in sign. Mean physical dominance rating is the average of each rater's physical dominance ratings of the vocal stimulus set. Relative physical dominance was calculated as the difference between self-rated physical dominance and the mean physical dominance rating given by each rater or as the difference between self-rated physical dominance and the rating of the standard competitor made by each participant providing voice recordings.

Statistical tests were two-tailed and considered significant at α=0.05. To maximize chances of detecting relationships in these exploratory analyses, statistical correction for multiple tests (e.g., Bonferroni correction) was not used.

Results

To examine whether men's dominance affects their attention to vocal masculinity, we linearly regressed attentiveness magnitude, attentiveness strength, and mean dominance rating on self-rated physical dominance, controlling for age, in separate models. We also tested whether men's attentiveness to vocal masculinity was curvilinearly related to self-rated dominance via quadratic regression. With age controlled, self-rated physical dominance (mean=62.0, SD=25.4) predicted mean physical dominance ratings of other men (β=−0.24, t_{86}=−2.29, p=0.024). Men who rated themselves higher in fighting ability rated other men lower, on average. Self-rated physical dominance linearly predicted neither the magnitude (β=−0.09, t_{86}=−0.79, p=0.435) nor the strength (β=−0.11, t_{86}=−1.02, p=0.313) of men's attentiveness to vocal masculinity. Quadratic regressions of magnitude and strength of attentiveness to vocal masculinity regressed on self-rated dominance were also statistically non-significant (p's>0.37).

Next, we examined whether self-assessed fighting ability predicted mating success. With age statistically controlled, self-rated relative physical dominance (mean=13.03, SD=28.38) predicted number of sex partners in the last year (β=0.46, t_{61}=3.89, p=0.001, mean sex partners=1.95, SD=1.32). Men who rated themselves as relatively better fighters reported more sex partners (Fig. 1). We also analyzed this relationship in the men who provided voice recordings and found a similar relationship (β=0.19, t_{101}=1.99, p=0.049; mean sex partners=1.35, SD=1.75; mean relative physical dominance=-0.31, SD=1.61).

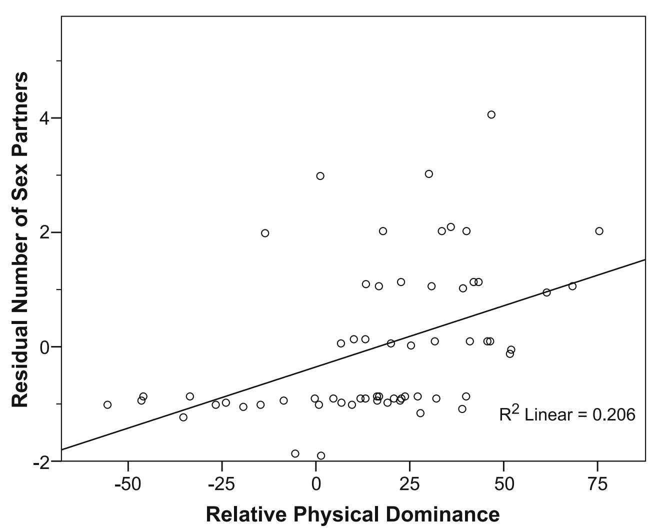

Fig. 1 Number of sex partners reported in the past year after controlling for age regressed on self-rated physical dominance (relative to mean rating given to others). Men who rated themselves high in physical dominance relative to others reported more sex partners (p<0.001). See main text for statistical details

A man's assessment of his own physical dominance is likely to be relevant to his success in competition for mates, as the above relationships between relative physical dominance and number of sex partners suggest. However, although self-rated physical dominance did not predict attentiveness to vocal masculinity, it is possible that more objective measures of raters' physical dominance would. We therefore examined such relationships in study II.

Study II

Materials and methods

Participants One hundred seventy-eight self-identified heterosexual male Michigan State University undergraduate students (mean age $= 20.14 \pm 1.7$, range=18–26) participated as raters in this IRB-approved study.

Stimulus set Voice stimuli were produced from recordings of six young men reading a sentence (approximately 6 s in duration) from the Rainbow Passage (Fairbanks 1960) in an anechoic, soundproof booth using a Shure SM58 vocal cardioid microphone. A curved wire projection from the microphone stand kept the participant's mouth a standard 9.5 cm from the microphone. Voices were recorded using Goldwave software in mono at a sampling rate of 44,100 Hz. Each of the recordings was digitally analyzed using Praat voice analysis software (version 4.4.11). All settings were in accordance with the programmers' recommendations for adult male voices (Boersma and Weenik 2009). Formants were measured using the long-term average spectrum (Xue and Hao 2003; Gonzalez 2004), and D_f was computed by taking the average distance between each of the first four formants (Fitch 1997). For unmanipulated voices, mean F_0 was 109.9 (range=97.8–122.1, SD=10.0), and mean D_f was 1,003.5 (range=941.7–1,072.7, SD=51.6).

Recordings were then raised or lowered in both fundamental frequency (F_0) and formant dispersion (D_f) using Praat audio software. In order to study which vocal parameter had a greater impact on dominance perception, we manipulated F_0 and D_f separately for each voice and by an increment of one just noticeable difference (JND) up or down. JND was defined as the smallest increment in F_0 or D_f for which the average listener could perceive a difference 50% of the time and was obtained for F_0 and D_f in men's voices by Puts et al. (2007). For F_0, the JND was 1.2 semitones; for D_f, it was a 4% change. The six male voices used in this study were thus manipulated using Praat software to either increase or decrease F_0 by one JND, or increase or decrease D_f by one JND, thus creating a total of 24 stimulus voices for rating. Intensity was adjusted to 70 dB for all stimuli.

Procedures Participants were scheduled for two 1-h sessions approximately 1 week apart (6.99±0.72 days). One session was scheduled for the morning, and the other was scheduled for the evening. Morning sessions began between 0820 and 1000 hours, and evening sessions began between 1720 and 1900 hours. To maintain a consistent interval between morning and evening sessions, participants who were scheduled in the latter half of the morning testing session were also scheduled in the latter half of the evening session. The average time difference between morning and evening sessions was 8.95 h (±0.55). Session order was randomized so that equal numbers of participants were scheduled first in the morning as were scheduled first in the evening. Anthropometric and psychometric data were collected at both sessions.

Anthropometry Anthropometric measurements were made by a trained research assistant. Height was measured using a meter stick on a wall. Flexed biceps circumference was measured at its widest point for both the left and right arms using a tape measure. Biceps size correlates strongly with upper body strength and aggression (Archer and Thanzami 2007). Hand strength for both left and right hands was obtained using a JAMAR hydraulic hand dynamometer. Participants were instructed to hold the device with their arm at their side, elbow in and bent 90°, and encouraged to squeeze to obtain a maximum strength reading. Handgrip strength is a good predictor of overall physical strength (Bassey and Harries 1993; Rantanen et al. 1998; Gallup et al. 2007). Weight was obtained using an electronic scale.

Testosterone assays Saliva was collected for testosterone (T) assays during both morning and evening sessions. Contamination of saliva samples was minimized by having participants not eat, drink (except plain water), smoke, chew gum, of brush their teeth for 1 h before their scheduled session. Participants were instructed to rinse their mouths with water immediately before chewing a piece of sugar-free Trident gum (inert in salivary hormone assays) to stimulate saliva flow before collection. Approximately 9 ml of saliva was collected in a sodium azide-coated polystyrene tube. The tube was capped and allowed to stand upright at room temperature for 18–24 h to allow mucins to settle. Tubes were then frozen at −20°C until hormone analysis.

We obtained salivary unbound ("free") T concentrations, which correlate strongly with serum T concentrations (e.g., Baxendale et al. 1980; Wang et al. 1981, r=0.81 and 0.94, respectively). The Salivary Radioimmunoassay Laboratory at the University of Western Ontario performed T radioimmunoassays on 333 male saliva samples, 177 from session 1 and 156 from session 2. All samples went through a double ether extraction, followed by a radioimmunoassay in duplicate using a Coat-A-Count kit for total T (Diagnostic Products, Los Angeles, CA, USA), modified for use with saliva. For details, see Moffat and Hampson (1996). The average intra-assay coefficient of variation was 6.3%, and sensitivity was 5–10 pg/ml.

Psychometric data collection Following collection of anthropometric measurements and saliva, each rater was seated at a computer station with a headset. Cubicle dividers separated computer stations to ensure independent results. Raters completed a series of computerized questionnaires targeting demographic data. Raters then listened to the 24 male voice stimuli, which were played in a constant order to facilitate comparison across sessions. Order was counterbalanced within the stimulus set, so that for half of the voices the masculinized version was played first. The raters were instructed to indicate their agreement with the statement: “If this man got into a fistfight with an average male undergraduate student, this man would probably win.” A 10-point Likert scale labeled strongly disagree (1) and strongly agree (10) was used for ratings. Finally, raters completed the Buss and Perry (1992) Aggression Questionnaire comprising of 29 questions that target anger (seven items), hostility (eight items), physical aggression (nine items, e.g., “Once in a while I can’t control the urge to strike another person”), and verbal aggression (five items). The items were ranked on a 5-point scale, anchored at “extremely uncharacteristic of me” and “extremely characteristic of me.” Scores are summed up for items targeting each type of aggression, but only physical aggression scores were used in the present study.

Statistical analyses Because of the number of variables and relationships (e.g., linear vs. curvilinear) examined, multivariate tests and data reduction methods (e.g., factor analysis) were used wherever possible. Statistical tests were two-tailed and considered significant at $\alpha=0.05$. To maximize chances of detecting relationships in these exploratory analyses, statistical correction for multiple tests (e.g., Bonferroni correction) was not used.

Results

Objective measures of physical formidability (height, weight, biceps circumference, hand strength, and physical aggression) were highly correlated between sessions 1 and 2 ($0.69<r<0.99$). Left and right hand strength and biceps circumference were also highly correlated within sessions ($0.75<r<0.96$). Hence, we averaged measurements from sessions 1 and 2, and from left and right sides, as presented in Table 1. T concentrations (log-transformed to correct skewness) were also significantly correlated across morning and evening sessions ($p=0.0001$), although the correlation was more modest ($r_{156}=0.42$), as expected given temporal variability in T secretion. T concentrations also decreased significantly from morning to evening sessions (paired $t_{155}=10.8$, $p=0.0001$), indicating that we were able to capture significant diurnal variation. Because we were interested in trait T levels for this study, we averaged morning and evening T concentrations.

To examine the effects of vocal masculinity on dominance ratings, we performed a mixed-model repeated measures ANOVA with four factors: session (session 1 or 2), speaker (six individual speakers), acoustic parameter (F_0 or D_f), and manipulation (raised or lowered). Increasing vocal masculinity (lowering F_0 or D_f) significantly increased dominance ratings relative to decreasing vocal masculinity ($F_{153,1}=360.0$, $p=0.0001$, partial $\rho^2=0.70$). There was a significant difference in the effects of F_0 and D_f on dominance ratings (acoustic parameter × manipulation interaction, $F_{153,1}=72.4$, $p=0.0001$, and partial $\rho^2=0.32$). Post hoc tests revealed that F_0 influenced perceptions of physical dominance ($F_{1,155}=359.2$, $p=0.0001$, and partial $\rho^2=0.70$) to a greater degree than did D_f ($F_{1,153}=159.3$, $p=0.0001$, and partial $\rho^2=0.51$; see Fig. 2).

To examine possible effects of each rater’s physical formidability on the average dominance rating that he gave, we first performed a principal component analysis (PCA) on measures of physical formidability, extracted the four components with eigenvalues >1, varimax-rotated these components, and then saved them as variables. These four components explained a combined total of 76.4% of

Table 1 Study II mean physical measurements

Physical characteristics	Mean	Range	SD
Height (mean sessions 1 and 2)	178.8 cm	164.2–197.3 cm	6.8 cm
Weight (mean sessions 1 and 2)	78.7 kg	53.1–290.7 kg	13.9 kg
Biceps circum. (mean L, R and sessions 1 and 2)	33.6 cm	26.1–44.0 cm	3.3 cm
Hand strength (mean L, R and sessions 1 and 2)	49.4 kg	22.5–69.3 kg	8.0 kg
Physical aggression score (mean sessions 1 and 2)	21.5	9.5–37.0	6.6
T Level (mean sessions 1,2)	92.3 pg/ml	36.3–254.5 pg/ml	33.0 pg/ml
Log (T) level (mean sessions 1 and 2)	4.43 pg/ml	3.56–5.52 pg/ml	0.33 pg/ml

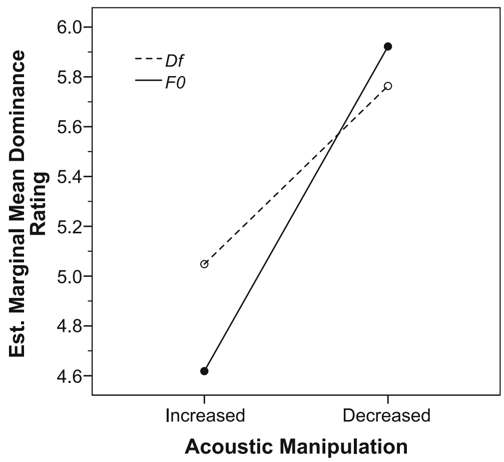

Fig. 2 Formant dispersion (D_f) and fundamental frequency (F_0) negatively affected perceptions of physical dominance (both p's< 0.0001). See main text for statistical details

the variance. Biceps circumference, weight, and hand strength loaded heavily onto the first factor, height loaded onto the second factor, age loaded positively and physical aggression loaded negatively onto the third factor, and T loaded heavily onto the fourth factor (Table 2). The four factors were entered into a linear multiple regression model to predict average dominance rating given. The model was not significant nor did any factor explain a significant portion of the variance (all $|t|<1.4$, all $p>0.16$). We then entered the four factor scores individually into quadratic regression models to predict mean dominance rating given. Factors 1–3 did not significantly predict dominance ratings given (all $p>0.49$). However factor 4 (the factor onto which T levels loaded heavily) significantly predicted mean dominance rating given ($F_{148,2}=5.6$, $p=0.005$). A quadratic regression of mean dominance rating on rater's mean T level confirmed this association ($F_{153,2}=4.4$, $p=0.014$). Men with either high or low T levels rated other men as more dominant, whereas men with average T levels rated them lower in dominance.

Next, we explored whether each rater's physical formidability linearly influenced his attention to vocal masculinity when making dominance assessments. To do so, we performed a series of mixed-model repeated measures ANOVAs with three factors: session (session 1 or 2), speaker (six individual speakers), and manipulation (raised or lowered) for both F_0 and D_f manipulations separately. Into each model, we added a measure of formidability (age, height, weight, biceps circumference, hand strength, testosterone levels, or physical aggression) as a covariate to gauge its effect on the relationship between vocal masculinity and dominance ratings (manipulation×formidability measure interaction). All measures of formidability were statistically non-significant in predicting attentiveness to vocal masculinity when rating physical dominance (all $F<2.7$ and $p>0.1$; see Table 3). Changes in T levels between sessions 1 and 2 also did not predict changes in attentiveness to vocal masculinity (session×manipulation×T change interaction: F_0, $F_{1,152}=2.68$ and $p=0.104$; D_f, $F_{1,152}=0.81$ and $p=0.369$).

Finally, we tested whether men's attentiveness to vocal masculinity was curvilinearly related to formidability. To accomplish this, we calculated two measures of attentiveness to vocal masculinity for each rater by first computing the paired t statistics comparing his ratings of voices lowered to those raised in F_0 and D_f. These t statistics were then converted into correlation coefficients (r values), which served as our measures of individual raters' attentiveness to F_0 and D_f, analogous to measures of attentiveness strength in study 1. Separate sets of quadratic regressions were performed with attentiveness to F_0 and D_f as dependent variables and age, height, weight, biceps circumference, hand strength, testosterone levels, and aggression as predictor variables. No regression was statistically significant (all $p>0.35$, see Table 4).

Discussion

Study I

In a previous analysis of the rating data from study 1 of the present paper, Puts et al. (2006) reported that vocal

Table 2 Component loadings of first four varimax-rotated components of PCA

	Component			
	1 EV=2.1, 30.1%	2 EV=1.1, 15.7%	3 EV=1.1, 15.5%	4 EV=1.1, 15.2%
Age	0.155	−0.102	0.889	−0.128
Log (T) Mean	0.096	−0.094	−0.067	0.932
Mean Bicep Circum.	0.898	−0.100	0.078	−0.044
Mean Hand Strength	0.690	0.145	−0.030	0.151
Mean Phys. Aggr.	0.452	−0.239	−0.529	−0.381
Mean Weight	0.748	0.370	0.047	−0.030
Mean Height	0.158	0.925	−0.045	−0.075

EV = Eigenvalue, percentages refer to the amount of variance explained.

Table 3 Interactions between effect of vocal masculinity (F_0 or D_f) and characteristics of the rater on dominance ratings

	Fundamental frequency (F_0)			Formant dispersion (D_f)		
	df	*F*	*p*	*df*	*F*	*p*
Age	1, 154	0.57	0.451	1, 152	3.27	0.072
Height	1, 154	2.65	0.106	1, 151	0.11	0.746
Weight	1, 154	0.01	0.923	1, 152	0.07	0.788
Biceps circumference	1, 153	1.78	0.184	1, 151	0.55	0.459
Hand strength	1, 152	0.06	0.809	1, 150	1.41	0.237
Physical aggression	1, 154	1.37	0.244	1, 152	1.21	0.273
Trait testosterone levels	1, 152	0.03	0.854	1, 150	0.06	0.807
Change in T levels (three-way interaction with session)	1, 152	2.68	0.104	1, 150	0.81	0.369

masculinity strongly increased perceptions of dominance. Using these data, we report a relationship between a man's perception of his own physical dominance and his perceptions of other men's dominance based on their voice recordings. Men's self-rated physical dominance did not affect their attentiveness to vocal masculinity when assessing other men's dominance; however, men who rated their own dominance highly tended to rate other men's dominance lower. Self-rated physical dominance also positively predicted number of sex partners in the past year for two separate groups of men. It is possible that this relationship was found because of similar reporting biases on both variables or because men who had sex with more women consequently rated their own dominance more highly. However, men's reported number of sex partners is also positively related to dominance ratings of their voices made by other men (Puts et al. 2007). In addition, objective measures of physical dominance, such as strength (Lassek and Gaulin 2009) and height (Mueller and Mazur 2001), and measures of social dominance (Chagnon 1988; Perusse 1993) predict components of mating success in contemporary populations.

It would have been desirable in study I to ensure independent ratings by separating raters physically. However, raters conformed to instructions not to react visibly or audibly to recordings, and similar results were obtained, both in effects of vocal masculinity on dominance ratings and lack of effects of rater's dominance on attentiveness to vocal masculinity, in study 2 (see below), in which raters were separated physically.

Study II

Manipulations in F_0 and D_f had large independent effects on perceptions of dominance. F_0 was found to have a larger impact on dominance ratings than did D_f, in contrast to the results of Puts et al. (2007). Reasons for this difference might include a larger sample in the present study, manipulations of different magnitudes, and the fact that each individual rating of physical dominance was used in the present analyses, whereas Puts et al. (2007) averaged the ratings given to each stimulus voice. Additionally, Puts et al. (2007) randomized the order of stimulus presentation across subjects, whereas a constant order was used in the present study. However, we found no effect of presentation order on the effect of vocal masculinity, after controlling for speaker identity and acoustic parameter. Perhaps most importantly, in the present study, raters heard each manipulation of each voice, and all recordings were of the same standard passage. In contrast, Puts et al. (2007) used spontaneous utterances collected during a competitive interaction, and each rater did not hear more than one manipulation of any given voice. The methods of Puts et al. (2007) more closely mirror the natural conditions under which men compete verbally, whereas the present methods are more similar to those used in most studies of the effects of masculinity on dominance and attractiveness (Feinberg et al. 2005; Little et al. 2007b; Roberts et al. 2009). It is possible that the effects of verbal content on dominance

Table 4 Quadratic relationships between attentiveness to vocal masculinity (F_0 or D_f) and characteristics of the rater

	Fundamental frequency (F_0)			Formant dispersion (D_f)		
	df	*F*	*p*	*df*	*F*	*p*
Age	2, 175	0.64	0.526	2, 174	0.16	0.856
Height	2, 154	0.65	0.525	2, 154	0.31	0.735
Weight	2, 154	0.21	0.812	2, 155	0.01	0.990
Biceps circumference	2, 154	0.84	0.432	2, 154	1.04	0.358
Hand strength	2, 153	0.39	0.677	2, 153	0.45	0.638
Physical aggression	2, 154	0.20	0.816	2, 153	0.11	0.898
Trait testosterone levels	2, 153	0.02	0.978	2, 153	1.01	0.365

ratings reduce the impact of F_0 to a greater extent than D_f. These discrepant results highlight the importance of conducting both tightly standardized laboratory studies that maximize the chance of finding significant effects and more ecologically valid studies that better estimate the contributions of the traits of interest to dominance and attractiveness in natural settings.

None of the physical dominance measures collected in study II linearly or curvilinearly predicted men's attentiveness to vocal masculinity when assessing physical dominance. No variable except for trait T level predicted mean dominance rating in quadratic regression models. Men with intermediate T levels rated other men lower in dominance, whereas men with either high or low T levels rated more highly. Although it is possible that we obtained this result because men with either high or low testosterone tended to use the high ends of scales, we can think of no reason why T would lead to such a general response bias. Quadratic relationships between mean dominance ratings and objective measures of dominance were examined for completeness, and thus our interpretation of this result will necessarily be post hoc. However, T levels are also curvilinearly related to depression in men, with average T levels associated with the most positive mood (Booth et al. 1999), so it is possible that men with either high or low T levels are more negative about themselves generally and tend to rate other men higher on various positive traits, including dominance. Future research should explore this interesting association.

A possible shortcoming of this study is that, whereas a previous study demonstrated that males show condition-dependent perception of dominance when their female partner was in the high conception period of her menstrual cycle (Burriss and Little 2006), we did not ask the participants about whether they were currently in a relationship and, if so, their partner's reproductive status. Had we done so, this might have revealed interesting patterns.

General discussion

The present paper is the first to replicate the finding of Puts et al.'s (2007) that F_0 and D_f exert independent effects on perceptions of dominance among men. To our knowledge, this is also the first paper to show that self-rated physical dominance negatively predicts dominance ratings of other men's voices and positively predicts number of sex partners, and we were able to show the latter result in two samples of men. This is also the first paper to obtain the intriguing result that dominance attributions are curvilinearly related to trait testosterone levels.

The principal finding of the present paper was that vocal masculinity had large effects on the appearance of dominance that were not modulated by the dominance of the perceiver. This was shown in two studies, one using self-rated physical dominance and the other examining more objective measures of physical dominance. Physical parameters, such as height, weight, and musculature, are some of the most obvious cues of fighting ability (Sell et al. 2009). In a wide range of animals, size accurately predicts which opponent is likely to initiate an attack, withdraw, or win an aggressive encounter (Archer 1988). In humans, physical size has been associated with dominance among early adolescents (Tremblay et al. 1998) and adults (Felson 1996). Aggression is another indicator of dominance (Mazur and Booth 1998). Physical aggressiveness is positively related to androgen level (Archer 1991; Mazur and Booth 1998; Harris 1999; Ramirez 2003) and physical prowess (Clark and Henderson 2003). The relationship between dominance and testosterone is bidirectional; not only may testosterone levels affect dominant behavior (Carre et al. 2009), but circulating androgen levels can also change rapidly in response to recent aggressive behavior (Adkins-Regan 2005). Testosterone increases in winners and decreases in losers in contest situations (Carre 2009). A weak association has been found between size, strength, and direct aggression in men (Archer and Thanzami 2009). However, neither self-rated physical dominance nor size, strength, muscularity, aggression, or testosterone levels predicted men's attentiveness to vocal masculinity when making dominance assessments.

These results may attest to the robustness of vocal masculinity as a dominance signal and suggest a cognitive architecture for assessing vocal masculinity that does not depend on an observer's own dominance. Men who rated themselves high in dominance and those with intermediate testosterone levels tended to rate other men lower in dominance on average. Thus, variables related to a man's own dominance predict his assessments of other men's dominance, even though they do not predict his attentiveness to vocal masculinity when making these assessments.

A possible explanation for this pattern of results is that the mean dominance rating given by a man reflects his perceptions of other men's dominance relative to his own, whereas his attentiveness to vocal masculinity when assessing other men reflects his perceptions of these men relative to each other. Men who perceive themselves to be high in dominance, or perhaps those with a generally positive outlook associated with intermediate T levels, may tend to rate other men lower on dominance. This tendency could function in enabling men to achieve and maintain dominance if in good condition and avoid dominance contests if in poor condition. However, the assessment of other men's dominance in relation to each other may function partly in determining with whom to form alliances. Accurately determining higher and lower dominance men allows a male to align himself with the most dominant males within a social hierarchy, and potentially gain better access to mates and resources. This hypothesis will require clever approaches to testing, as the rarity of male coalitions will impede cross-species comparison. Future research in humans should examine whether dominance influences assessment of other potential dominance cues, such as facial hair, facial masculinity, muscularity, and stature.

Acknowledgments We thank Robert Burriss for helpful suggestions on statistical analyses and comments on the manuscript; Bradly Alicea, Michael Burla, Lisa Brevard, Rodrigo Cárdenas, Rachel Chandler, Melina Durhal, Rebecca Frysinger, Christina Jerzyk, Sana Khan, Jerome Lee, Mallory Leinenger, Erin MacCourtney, Heather Malinowski, Ernestine Mitchell, Joe Morehouse, Rebecca Prosser, John Putz, Melinda Putz, Linda Snyder, Sara Sutherland, Lisa Vroman, Tyesha Washington, and Molly Zolianbawi for their conscientious assistance in study preparation and data collection; Julio Gonzalez and Drew Rendall for their advice on measuring formant frequencies; Elizabeth Hampson and Bavani Rajakumar for their assistance with hormone assays; and Marc Breedlove, Steven Gaulin, Cynthia Jordan, and Kittie Verdolini for providing research support.

Ethical standards Experiments conducted in the present study comply with the current laws of the country in which they were performed.

Conflict of interest The authors declare that they have no conflict of interest.

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