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Original Article

The evolved psychology of voice: evaluating interrelationships in listeners' assessments of the size, masculinity, and attractiveness of unseen speakers☆

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Abstract

A growing body of research has examined how voice characteristics advertise personal dimensions relevant in mate competition and mate choice. This work has centered on two key voice features, namely, fundamental frequency (F_0) and formants (Fn), and has consistently found that speakers with low F_0, low Fn, or both are rated as being larger, more masculine, and more attractive if men but less attractive if women. However, this consistency in listeners' perceptions is not matched by an equivalent consensus in how these mate-relevant dimensions are causally related or signaled by voice characteristics. Consequently, it is critical to test whether the strong correlations in listeners' perceptions reflect reliable causal relationships between these dimensions or, alternatively, whether they reflect some perceptual or cognitive nonindependence, for example, "what is large is masculine" and "what is small is feminine." To test this latter possibility, we report detailed analyses of interdependence in listeners' ratings of perceived size, masculinity or femininity, and attractiveness of natural and manipulated voices of the opposite sex. We found strong correlations in listeners' ratings of all three dimensions, confirming past research. Principal component analysis corroborated these interrelationships but also revealed some independence in women's ratings of men's attractiveness and additional (but weaker) independence in men's ratings of women's size. We discuss possible implications for future research on the evolved psychology of voice and whether and how it reflects adaptive functional heuristics for discriminating mates.

Keywords: Voice; Perception; Attractiveness; Body size; Masculinity and femininity; Fundamental frequency; Formants; Sexual selection; Mate choice

1. Introduction

There has been a recent surge in voice-related research in evolutionary psychology focused on the role that voice characteristics might play in advertising personal dimensions relevant in mate competition or mate choice (Feinberg, 2008). This trend is a natural outgrowth of the longer history of related research on the face, which is hypothesized to be a target of sexual selection and to play an important role in people's assessments of relevant characteristics of potential rivals or mates (Fink & Penton-Voak, 2002; Perrett, 2010; Perrett et al., 1998; Rhodes, 2006). Both the voice and face are sexually dimorphic traits, and their development depends in part on pubertal exposure to hormones (e.g., testosterone) and, as such, might provide cues to an individual's health or quality (Feinberg, 2008; Gangestad & Scheyd, 2005; Thornhill & Gangestad, 1999).

Previous research on listeners' assessments of unseen speakers has produced a variety of interesting findings, among the most consistent being strong correlations in listeners' ratings of different mate-relevant dimensions, such as body size, masculinity or femininity, and overall attractiveness (Bruckert, Liénard, Lacrois, Kreutzer, & Leboucher, 2006; Collins, 2000; Feinberg, Jones, Little, Burt, & Perrett, 2005; Feinberg, DeBruine, Benedict, & Perrett, 2008; Hodges-Simeon, Gaulin, & Puts, 2010; Hughes, Dispenza, & Gallup, 2004; Jones, Feinberg, DeBruine, Little, & Vukovic, 2010). Specifically, men tend to rate small-sounding women as being

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more feminine and also as being more attractive, while women tend to rate men who sound bigger as being both more masculine and more attractive. These patterns certainly confirm lay intuitions and are commensurate with some theoretical predictions; however, they also conceal some fundamental ambiguities that need to be resolved.

1.1. Ambiguities in past voice-based research

The consistency observed in people's voice-based ratings of mate-relevant dimensions of unseen speakers is not matched by an equivalent consensus in our understanding of how the voice characteristics involved reliably signal these different dimensions. Research to date has focused on two independent voice traits, namely, voice fundamental frequency (F_0) and the pattern of voice resonances, or formants (Fn). Voice F_0 is closely associated with the percept of pitch and is traceable to the size and mass of the vibrating vocal folds of the larynx (Lieberman & Blumstein, 1988; Titze, 1994). The pattern of voice Fn is associated with the percept of timbre and results from the way laryngeally produced sounds are filtered by the cavities above the larynx (e.g., vocal tract and oral cavity) that leave a characteristic resonance imprint on the sounds produced (Ghazanfar & Rendall, 2008).

One of the most consistent findings is that listeners rate unseen speakers as being larger if their voices are characterized by low F_0, low Fn, or both (Bruckert et al., 2006; Collins, 2000; Collins & Missing, 2003; Feinberg, Jones, Little et al., 2005; Greisbach, 1999; Rendall, Kollias, Ney, and Lloyd, 2007; Smith, Patterson, Turner, Kawahara, & Irino, 2005; Van Dommelen & Moxness, 1995). However, these two voice traits are not, in fact, equally good predictors of body size. Both voice F_0 and Fn differ consistently between adult men and women, who often do differ in size. However, within age–sex classes, which are where assessments of rivals or potential mates are most relevant, most studies have found no reliable correlation between F_0 and body size (Collins & Missing, 2003; Evans, Neave, & Wakelin, 2006; Künzel, 1989; Majewski, Hollien, & Zalewski, 1972; Rendall et al., 2005; Sell et al., 2010; Van Dommelen & Moxness, 1995), although Puts, Apicella, and Cardenas (2011) recently reported a positive relationship between F_0 and height in adult men that might be attributed to the comparatively large sample (n=175) used in this study. In contrast, Fn tends to correlate better with body size variation within adult men and within adult women (Collins & Missing, 2003; Greisbach, 1999; González, 2004; Rendall et al., 2005), likely because of an associated correlation with overall vocal tract length (Fitch, 2000). Hence, for individuals assessing the size of potential rivals or mates (i.e., making within-sex body size judgements), the cues provided by Fn appear much more reliable than those provided by F_0.

Similar ambiguities characterize voice-based ratings of masculinity and femininity. Listeners consistently rate speakers of either sex with low F_0, low Fn, or both as being more masculine or less feminine (Bralley, Bull, Gore, & Edgerton, 1978; Collins, 2000; Feinberg, Jones, Little et al., 2005, Feinberg et al., 2008). However, here again, the two voice traits are not equally reliable predictors of masculinity and femininity (Coleman, 1976). Although there are differences in the average value of both F_0 and Fn between the sexes, the magnitude of the differences is widely divergent: there is a twofold difference in voice F_0 between men and women, with very little overlap in the distributions of the two sexes, but a difference of only 15%–20% in voice Fn between men and women, with considerable overlap in the distributions of the sexes (Bachorowski & Owren, 1999; Peterson & Barney, 1952; Rendall et al., 2005).

At the same time, there is evidence that some of the variation in F_0 within adults of both sexes is influenced by sex-specific hormones (Abitol, Abitol, & Abitol, 1999; Dabbs & Mallinger, 1999; Evans, Neave, Wakelin, & Hamilton, 2008; Puts, Apicella et al., 2011), with no similarly direct connection between sex-specific hormones and variation in Fn within sexes (but see Bruckert et al., 2006). Because hormonally mediated changes in voice F_0 in men at puberty are also associated with a small secondary descent of the larynx that slightly increases overall vocal tract length, it is possible that Fn cues could also signal variable masculinity (Fitch & Giedd, 1999). However, there is as yet no direct evidence that the extent of this secondary laryngeal descent varies as a function of varying testosterone profiles or that it varies at all among men. Hence, for individuals assessing masculinity or femininity within sexes, the cues provided by F_0 appear to be more reliable and salient than those provided by Fn.

1.2. Dissecting the problem

Understanding the adaptive basis of voice-based assessments of prospective mates or rivals thus entails three interrelated issues, depicted graphically in Fig. 1. First, what are the principled causal relationships among the frequently studied dimensions of body size, masculinity or femininity, and perceptions of attractiveness? Are larger men truly more masculine than shorter men? Are smaller women inherently more feminine than larger women? Second, to what extent are these mate-relevant dimensions reliably manifest in the voice? And third, irrespective of the principled causal relationships involved, how are the different mate-relevant dimensions perceived and interpreted by listeners?

We need answers to all three issues. There is active research on the first two, and so, in this paper, we focus specifically on the third issue, namely, establishing the interindependence in listeners' perceptions of mate-relevant dimensions. The importance of this particular emphasis lies in helping to better establish what exactly it is about potentially evolved voice preferences that requires explanation. For example, if it turns out that, despite the consistently correlated nature of listeners' perceptions of different mate-relevant dimensions, listeners are in fact able to rate the different

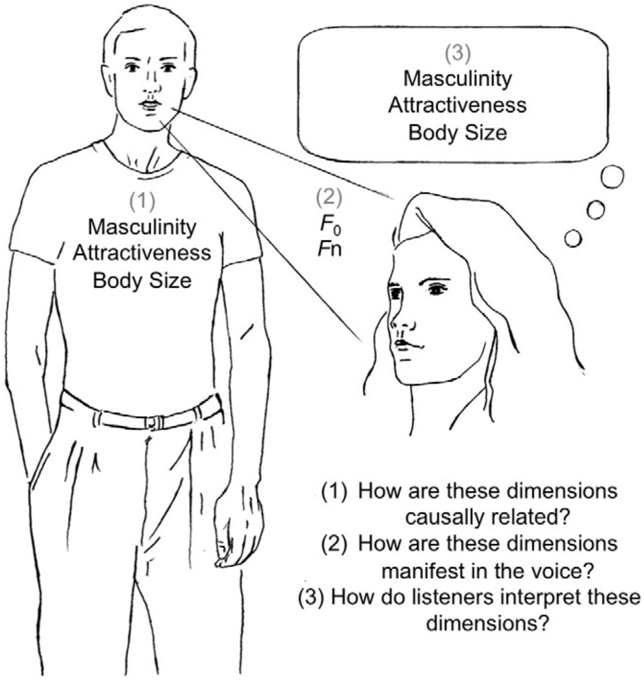

Fig. 1. Three interrelated issues concerning the potential adaptive basis of voice-based assessments of prospective mates.

dimensions independently, then our focus needs to be on understanding exactly how these different dimensions are causally related to one another and reliably manifested in the voice because research to date has not conclusively established those connections. In contrast, if it turns out that listeners' ratings of various mate-relevant dimensions are not actually independent of one another, then what requires explanation might be quite different. In that case, future research will need to focus on why listeners treat these dimensions as being related even when, in reality, they may not be.

To address these issues, we build on results of a previous study where men and women rated speakers of the opposite sex on body size, masculinity or femininity, and attractiveness (Pisanski & Rendall, 2011). Listeners rated speakers exemplifying natural variation in F_0 and Fn and several manipulated versions of these speakers where the F_0 and Fn characteristics had been modified in opposition to one another (i.e., low F_0 combined with high Fn and high F_0 combined with low Fn). The conflict between the two was made in amounts that were equally perceptually discriminable to listeners as established in a parallel study that quantified just-noticeable differences (JNDs) in listeners' discrimination of small frequency differences in each voice feature. These mixed voice stimuli forced listeners to reveal their commitment either to F_0 cues or to Fn cues when rating body size, masculinity or femininity, and attractiveness.

Based on the balance of previous work, a priori predictions were that ratings of masculinity or femininity would track the much larger differences between sexes in voice F_0, while ratings of body size would track the more reliable size cues conveyed by voice Fn. Furthermore, Pisanski and Rendall predicted that, if size and masculinity are truly different dimensions of relevance in mate choice decisions and are differentially cued by Fn and F_0, then listeners' ratings of attractiveness would reflect a balance of the two voice features and not simply correlate with one or the other. As a result, the conflicting effects of F_0 and Fn in the mixed voice stimuli should cancel each other and yield no consistent effects in listeners' attractiveness ratings of these voices. In fact, listeners preferentially tracked Fn in rating all three dimensions. In this paper, we extend analysis of this work specifically to evaluate the potential independence or nonindependence of listeners' ratings of size, masculinity, and attractiveness.

2. Methods

2.1. Voice recording

Voices used as experimental stimuli were derived from recordings of undergraduate students at the University of Lethbridge collected 2 years earlier. Speakers were recorded in a sound-controlled room in the Lab of Comparative Communication and Cognition using procedures described in detail in Rendall et al. (2005) and Rendall, Vokey, and Nemeth (2007). Briefly, speech recordings were made using an adjustable head-mounted microphone (AKG C420) connected to a preamplifier and computer through a Butterworth antialias filter (Frequency Devices 900/9L8B). The speech material included a list of single-syllable words in bVt context (e.g., *bit, bet, bat, bait, butt, boot*).

2.2. Experimental stimulus construction

From the larger database, 20 speakers (10 males, 10 females) were selected for use in this experiment. Measurements of the fundamental frequency (F_0 or pitch) and the frequency of the first four formants ($F1$–$F4$) were obtained from the central, steady-state portion of the vowel sound in each word, using the pitch-tracking and formant-tracking functions of Praat (version 4.6, Boersma, 2001). These measures were then averaged across words within speakers to obtain mean F_0 and Fn values for each speaker. We used the absolute value of all four formants rather than the composite variable, formant dispersion, because the latter effectively omits potentially relevant information about the second and third formants (see Puts, Apicella et al., 2011; Rendall et al., 2005 for further discussion). For male speakers, the mean F_0 was 98 Hz (range: 82–117 Hz), and mean values for $F1$–$F4$ were 469, 1619, 2584, and 3511 Hz, respectively. For female speakers, the mean F_0 was 204 Hz (range: 178–236 Hz), and mean $F1$–$F4$ values were 586, 1949, 2969, and 4047 Hz, respectively. These values fell within the normal range for each sex (e.g., Bachorowski & Owren, 1999; Rendall et al., 2005; Stevens, 1998).

Experimental stimuli were constructed using the same words spoken by each speaker (*bet, butt, bite, beat, book*). Each word was separated by 50 ms of silence and standardized to 65 dB sound pressure level. Stimuli were grouped into two categories, with the first composed of the original natural recording of each speaker. The second category involved manipulated versions of the original recording for each speaker, in which the F_0 and Fn values were systematically modified. Four manipulations were performed for each speaker. The manipulations involved either increasing the F_0 of the voice and simultaneously decreasing each of the formants, or vice versa. In both cases, two such manipulations were performed in which voice F_0 and voice Fn were modified in opposite directions by perceptually equivalent amounts, defined as either two or three JNDs. JNDs were established in a previous experiment to be 6% from baseline values for F_0 in both male and female speakers and, for Fn, to be 6% for male speakers and 5% for female speakers.

2.3. Participants

Sixty-eight undergraduates (32 females, 36 males) completed the experiment and earned partial course credit. All participants included in the final sample self-identified as heterosexual.

2.4. Experimental procedure

Participants completed the experiment privately in a sound-controlled room via a custom computer interface designed in Runtime Revolution (v. 2.81). Before experimentation began, participants were instructed that they would hear a series of voices played to them one at a time and that they would be required to rate each speaker according to their apparent body size, masculinity/femininity, or attractiveness.

Voice stimuli were presented through Sennheiser HD 280 professional headphones at a standardized, preset volume. Participants made their ratings using a 6-point scale represented on screen by a set of six unlabeled radio buttons, three on either side of a midpoint marker that could not be selected. Each end of the scale was anchored by text labels that were, respectively, *small* and *large*, *feminine* and *masculine*, or *unattractive* and *attractive* depending on the dimension being evaluated on a particular trial. Each participant rated 10 different speakers of the opposite sex in each of five voice conditions: the original, unmanipulated voice recording and the four manipulated versions of the original recording. Each stimulus was rated on all three dimensions (size, masculinity/femininity, attractiveness), with only one dimension rated per trial. In total, each participant completed 150 trials (10 speakers×5 voice stimulus conditions×3 rating dimensions).

We undertook several precautions to minimize the possibility that nonindependence in listeners' ratings might arise simply because listeners tracked individual speakers across trials. Thus, the order of the different speakers and the different voice stimulus conditions was fully randomized within and between participants. In addition, trials were "blocked" by rating dimension for half of our participants to test an additional form of nonindependence in listeners' ratings, namely, that the rating of one speaker on a particular dimension might be affected by the immediately preceding ratings of several other speakers on that same dimension. Thus, for half of the participants, the order of the rating dimensions was fully randomized within and between participants (consequently, trials involving the same speaker were separated by 30 trials on average), while for the other half of participants, the rating dimensions were blocked so that participants rated multiple different voice stimuli on the same dimension (e.g., masculinity) before moving on to rate those same voice stimuli on another dimension (e.g., body size).

2.5. Statistical analysis

To test whether blocking treatment affected ratings, data were analyzed using a mixed analysis of variance model with speaker sex and voice condition as within-subjects factors and blocking treatment as a between-subjects factor. Following this, the degree to which listeners' ratings of the different dimensions were correlated or independent was evaluated in two ways. First, linear regression was used to test the strength of the association between rating dimensions in pairwise comparisons. Second, principal component analysis (PCA) was used to evaluate interrelationships among rating dimensions when considered simultaneously. Canonical PCA with no additional factor rotation was used to examine the degree of interdependence listeners' ratings of speaker body size, masculinity or femininity, and attractiveness with all of the variability in these rating dimensions included in the analysis (i.e., not just using their shared variance). We used a conservative factor loading score of ±0.71 as the criterion for inclusion of a particular rating dimension in a particular factor or component (Jolliffe, 2002; Tabachnick & Fidell, 1989). A factor loading score ≥±0.71 indicates that 50% (or more, i.e., the majority) of the variance in a variable is accounted for in that component. Regression analyses and PCA were implemented in NCSS v. 5.1 (Hintze, 2007).

3. Results

Overall, listeners' ratings varied significantly as a function of experimental frequency condition and rating dimension and included a significant interaction between the two, both for female listeners rating male speakers (analysis of variance, frequency condition: $F_{4,120}$=160.6, p<.001; rating dimension: $F_{2,60}$=90.17, p<.001; interaction term: $F_{8,240}$= 85.76, p<.001) and for male listeners rating female speakers (frequency condition: $F_{4,136}$=46.72, p<.001; rating dimension: $F_{2,68}$=6.72, p<.05; interaction term: $F_{8,272}$=112.72, p<.001). In neither case were ratings significantly affected by blocking treatment (female listeners: $F_{1,30}$=2.18, p=.15; male listeners: $F_{1,34}$=0.74, p=.40).

3.1. Regression analysis

There were significant levels of association between participants' ratings of size, masculinity, and attractiveness for all pairwise combinations of rating dimensions and for both natural and manipulated voice stimuli of both men and women (p<.05). Thus, male voices rated by women as sounding larger were also rated as being more masculine (natural voice stimuli: r^2=0.08; manipulated voice stimuli: r^2=0.5); male voices rated as sounding more masculine were rated as more attractive (natural: r^2=0.04; manipulated: r^2=0.07); and male voices rated as sounding larger were rated as more attractive (natural: r^2=0.03; manipulated: r^2=0.07).

The pattern of associations was the same for men's rating of women's voices except that, for certain comparisons, the effect ran in the opposite direction. Thus, female voices rated by men as sounding larger were also rated as more masculine, i.e., less feminine (natural: r^2=0.09; manipulated: r^2=0.29); female voices rated as more masculine were rated as less attractive (natural: r^2=0.17; manipulated: r^2=0.20); and female voices rated as sounding larger were rated as less attractive (natural: r^2=0.08; manipulated: r^2=0.18).

Taken together, women rated men who sounded larger as being both more masculine and more attractive, while men also rated women who sounded larger as being more masculine (less feminine) but less attractive. Overall, the associations were stronger between ratings of masculinity (or femininity) and ratings of body size than between ratings of either of these two dimensions and ratings of attractiveness.

3.2. Principal component analysis

These patterns were confirmed and further clarified by the results of PCA. Results are summarized in Table 1 for separate analyses of ratings of men's voices by women and ratings of women's voices by men, when they involved rating only natural, manipulated, or all voice stimuli (natural and manipulated) combined. In all cases, the variation in participants' ratings of the three different dimensions could be grouped into only two principal components that together accounted for between 76% and 90% of the total variance, thereby confirming considerable overlap in participants' ratings of at least two of the three dimensions. In some cases, all three rating dimensions were grouped together in a single component.

3.2.1. Men's voices

When women's ratings of the natural and manipulated voice stimuli of men were combined, PCA produced two components that collectively accounted for 89% of the total variance in participants' ratings. The first component had an eigenvalue of 1.80 and accounted for 60% of the total variance, and the second component had an eigenvalue of

Table 1
The first two components from PCA on participants' ratings of speaker body size, masculinity, and attractiveness

Voices	Component		Women's ratings of men's voices					Men's ratings of women's voices				
			Body size	Masculinity/ femininity	Attractiveness	Eigenvalue	Total variance accounted for by component	Body size	Masculinity/ femininity	Attractiveness	Eigenvalue	Total Variance accounted for by component
All	1	Factor loading[a]	**−0.87**	**−0.89**	−0.5	1.8	60%	**−0.8**	**−0.84**	**0.78**	1.96	65%
		Variable variance accounted for	0.76	0.79	0.25			0.65	0.7	0.62		
	2	Factor loading	−0.27	−0.22	**0.87**	0.87	29%	0.47	0.09	0.58	0.57	19%
		Variable variance accounted for	0.07	0.05	0.75			0.22	0.01	0.34		
Total variable variance accounted for			83%	84%	100%			87%	71%	96%		
Natural	1	Factor loading	**−0.71**	**−0.75**	−0.61	1.44	48%	−0.68	**−0.78**	**0.77**	1.66	55%
		Variable variance accounted for	0.51	0.56	0.37			0.46	0.61	0.59		
	2	Factor loading	−0.45	−0.2	**0.78**	0.85	28%	**0.73**	−0.27	0.37	0.74	25%
		Variable variance accounted for	0.2	0.04	0.61			0.53	0.07	0.14		
Total variable variance accounted for			71%	61%	98%			99%	68%	73%		
Manipulated	1	Factor loading	**−0.89**	**−0.89**	−0.54	1.87	62%	**−0.82**	**−0.83**	**0.77**	1.95	65%
		Variable variance accounted for	0.79	0.79	0.29			0.67	0.69	0.59		
	2	Factor loading	−0.25	−0.26	**0.84**	0.84	28%	0.34	0.24	0.64	0.59	20%
		Variable variance accounted for	0.06	0.07	0.71			0.12	0.06	0.41		
Total variable variance accounted for			85%	86%	100%			79%	75%	100%		

Results are presented separately for ratings of men's voices and ratings of women's voices and, within these, for ratings of natural voice stimuli, manipulated voice stimuli, and all voice stimuli combined.

[a] Factor loadings exceeding the criterion value of ±0.71 are shown in bold and indicate inclusion of a rating dimension in a particular component.

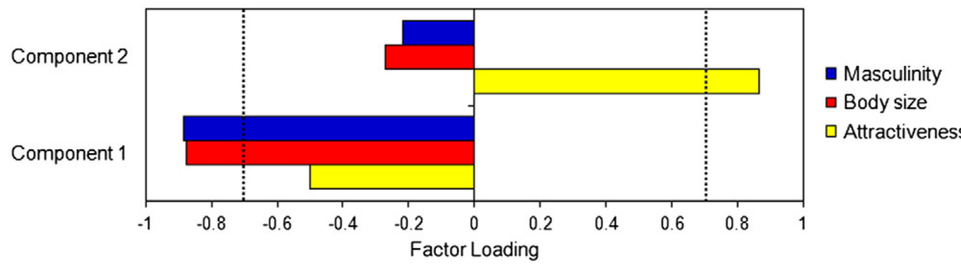

Fig. 2. PCA factor loadings for women's ratings of men's voices (natural and manipulated voices combined). The dotted line represents the factor loading cutoff point (±0.71) used to determine the association of particular dimensions with individual components.

0.88 and accounted for an additional 29% of the variance. Women's ratings of the body size and masculinity of men were both weighted heavily and in the same direction on the first component (factor loadings of −0.87 and −0.89, respectively) that encompassed nearly 80% of the variation in both dimensions (Fig. 2). In contrast, ratings of attractiveness were weighted heavily on the second component (factor loading=0.87) that accounted for 75% of the variation in this dimension. This pattern is confirmed in separate analyses conducted on ratings of only natural voice stimuli or only manipulated voice stimuli. In both cases, PCA produced two components in which women's ratings of the body size and masculinity of men's voices were grouped together on the first component that accounted for the majority (>50%) of the variance in the ratings of these two dimensions, while their ratings of attractiveness were substantially independent and were weighted heavily on the second component that accounted for the majority of the variance in attractiveness ratings (Figs. 3–4).

3.2.2. Women's voices

Results were slightly different for men's ratings of women's voices. Here, when ratings of the natural and manipulated voice stimuli were combined, PCA once again produced two components that collectively accounted for 84% of the total variance. However, most of this variation was accounted for in just the first component (first, 65% versus second, 19%), which had an eigenvalue of 1.95, weighted heavily all three rating dimensions, and accounted for the majority of the variance in each of the dimensions (Fig. 5). Thus, ratings of body size, femininity, and attractiveness were all characterized by factor loadings on the first component that were well in excess of the ±0.71 criterion (body size=−0.80, femininity=−0.84, attractiveness=0.78). In contrast, none of the rating dimensions had a factor loading in excess of ±0.71 on the second component. This outcome suggests substantial overlap and little independence in men's ratings of all three dimensions in women's voices.

This pattern was largely confirmed in separate analyses conducted on ratings of only natural voice stimuli or only manipulated voice stimuli in women. For ratings of manipulated voice stimuli, PCA produced two components that collectively accounted for 85% of the total variance in men's ratings of women's voices, but once again, most of this variation was accounted for by just the first component (first, 65% versus second, 19%), which had an eigenvalue of 1.95 and again weighted heavily all three rating dimensions and accounted for the majority of the variance in each of them (Fig. 6).

For men's ratings of natural voice stimuli in women, the pattern was very similar, with PCA producing two components that collectively accounted for 80% of the total variance, most of which was carried in the first component (first, 55% versus second, 25%). The first component was also strongly associated with all three rating dimensions and accounted for the majority of variance in each of them, with one exception (Fig. 7). For ratings of body size, in particular, the factor loading score fell just under the ±0.71 criterion for inclusion in the first component (−0.68) and just over the ±0.71 criterion for inclusion on the second component (0.73). Hence, the first component, which accounted for the majority of the variance in both femininity and attractiveness ratings (61% and 59%, respectively), also accounted for

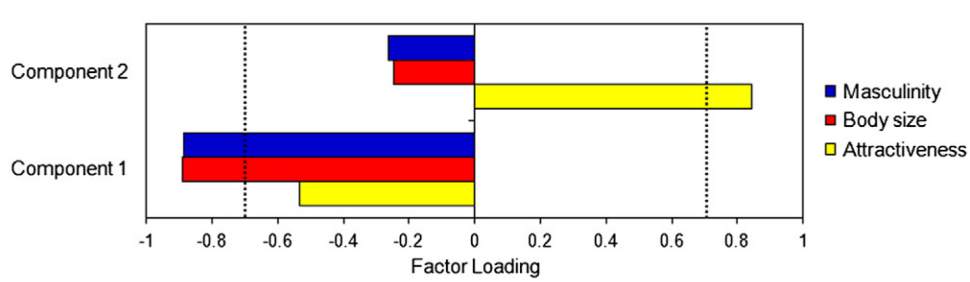

Fig. 3. PCA factor loadings for women's ratings of manipulated men's voices. Additional details as per Fig. 2.

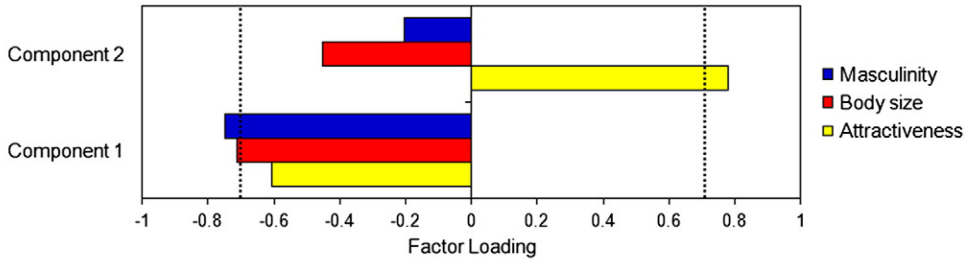

Fig. 4. PCA factor loadings for women's ratings of natural men's voices. Additional details as per Fig. 2.

46% of the variation in body size ratings. But the second component accounted for slightly more of the variation in this dimension (53%), which was therefore formally associated with the second component. The latter outcome suggests a degree of independence in men's ratings of the femininity and attractiveness of women speakers compared to ratings of their size.

4. Discussion

Our results reveal strong associations among listeners' ratings of the body size, masculinity or femininity, and attractiveness of opposite-sexed speakers. In regression analyses, all three dimensions were significantly and positively correlated in women's ratings of men's voices. Thus, men whose voices were rated by women as sounding larger were also rated as being more masculine and as more attractive. Body size and masculinity were also positively correlated in men's ratings of women's voices, and both were negatively correlated with ratings of attractiveness. That is, women rated as sounding larger were also rated as being more masculine (less feminine) and less (rather than more) attractive. In other words, men rated smaller and more feminine-sounding women as being more attractive. Collectively, these patterns agree well with past studies, many of which have likewise reported a general female preference for masculine or large-sounding male voices and a male preference for feminine or small-sounding female voices (Berry, 1990; Collins, 2000; Feinberg, Jones, DeBruine et al., 2005, Feinberg, Jones, Little et al., 2005, Feinberg et al., 2006, 2008; Pisanski & Rendall, 2011; Vukovic et al., 2008).

The PCA results further confirmed considerable shared variance among the three rating dimensions for both men and women. However, the PCA results also highlighted some substantial independence in women's ratings of the attractiveness of men's voices compared to their ratings of body size and masculinity (Figs. 2–4). There was also some weaker evidence that men's ratings of the body size of women might be independent of their ratings of women's femininity and attractiveness (Fig. 7).

Some previous studies have also noted variability or malleability in preference patterns, consistent with the results of our PCA. For example, past work has shown that although women's assessments of men's masculinity and attractiveness often correlate, women do not always prefer masculinity in men's features (Little & Hancock, 2002; Perrett et al., 1998; Rhodes, Hickford, & Jeffery, 2000). Whether women find masculine features attractive can depend on how attractive they themselves are or perceive themselves to be (Little, Burt, Penton-Voak, & Perrett, 2001; Penton-Voak, Little, Jones, Burt, Tiddeman, & Perrett, 2003; Vukovic et al., 2008), whether they are rating stimuli in the context of short-term or long-term relationships (Little, Jones, Penton-Voak, Burt, & Perrett, 2002; Penton-Voak & Perrett, 2000), and whether they are in the fertile or nonfertile phase of their menstrual cycle (Feinberg et al., 2006; Johnston, Hagel, Franklin, Fink, & Grammer, 2001; Puts, 2005). It is also possible that the relative independence of size and masculinity ratings from ratings of attractiveness in men's but not women's voices points to differences in the relative influence of intra- and intersexual selection in the two sexes. For example, Puts (2010) has proposed that men's voices might have been shaped more by intrasexual selection, while women's voices have been shaped more by intersexual selection. This account might be consistent with the strong correlations among all three dimensions in men's ratings of women's voices and the relative independence of women's

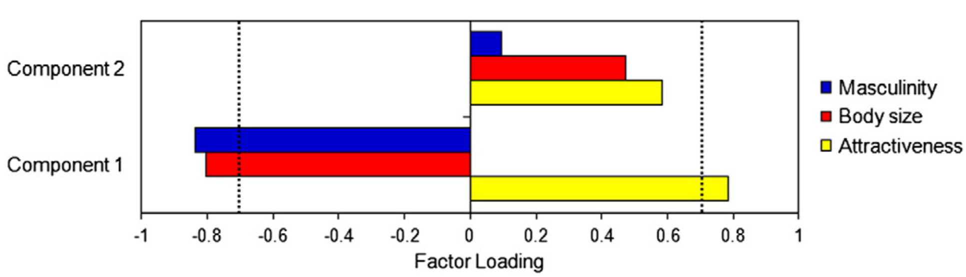

Fig. 5. PCA factor loadings for men's ratings of women's voices (natural and manipulated voices combined). Additional details as per Fig. 2.

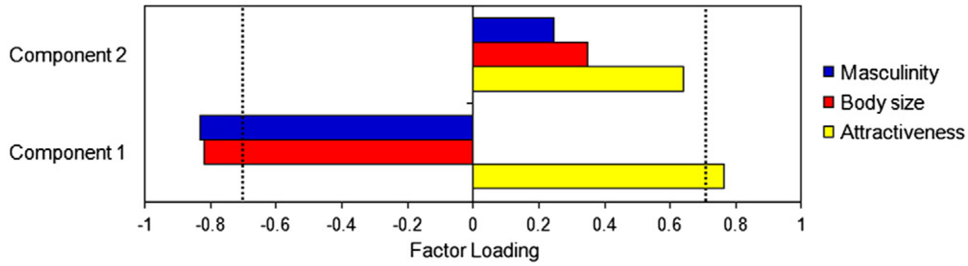

Fig. 6. PCA factor loadings for men's ratings of manipulated women's voices. Additional details as per Fig. 2.

attractiveness ratings of men's voices from their ratings of the size and masculinity of those men.

Also consistent with the results of our PCA, past studies have shown that size and attractiveness may not always be negatively correlated in men's ratings of women (Greenberg & LaPorte, 1996; Singh, 1994a; Swami & Tovée, 2009). One suggestion here is that the relationship between a woman's body form and attractiveness may be more heavily influenced by body shape than by overall size (Singh, 1994b), where larger women may be more attractive than smaller women if they exhibit a more preferred waist-to-hip ratio (Hughes et al., 2004; Hughes, Patizzo, & Gallup, 2008).

4.1. Are listeners able to rate mate-relevant dimensions independently?

Returning to the question that motivated this work, the short answer is "yes," at least to some degree, because results revealed some independence in women's ratings of the attractiveness of men's voices compared to their ratings of the size and masculinity of these speakers. This finding suggests that women's perceptions of size and masculinity in men do not wholly explain their perceptions of male attractiveness. At the same time, there was an additional, albeit much smaller degree of independence between men's ratings of the body size of female speakers and their ratings of the femininity and attractiveness of these speakers. This finding suggests that men's perceptions of a woman's femininity and attractiveness overlap to a considerable degree and, to a large extent, coincide with their perceptions of size, but that they are perhaps not entirely dependent on perceptions of size. Together, these two outcomes suggest that listeners' ratings involve at least some degree of independence and that this independence in ratings may reflect evolved preferences.

However, there is also some reason to be cautious in this conclusion. Despite some degree of independence, our results demonstrated strong interdependence in listeners' ratings of size and masculinity or femininity, regardless of the sex of the speaker, as well as interdependences among men's ratings of women's size, femininity, and attractiveness. Given these strong interrelationships in listeners' ratings of the different dimensions, it is possible that they reflect a kind of nonindependence in listeners' perceptions and interpretation of the different dimensions. Such interdependence might mean that rating voices of the opposite sex on some of these dimensions is essentially the same task. For example, it might be that, for women, "what sounds large is also masculine" and for men, "what sounds small is also feminine and attractive," regardless of whether these associations are reliable.

It is not clear which of the dimensions might anchor these perceptual associations and thus whether the ordering of the associations here should be reversed (e.g., "what sounds masculine is also assumed to be large"). However, it has been hypothesized that discriminations of size might have priority generally because size is a salient dimension of discrimination not just in mate choice (Lindenfors, Gittleman, & Jones, 2007; Mueller & Mazur, 2001; Nettle, 2002a, 2002b; Pawlowski, Dunbar, & Lipowicz, 2000) but in other social contexts (Ohala, 1983; Schumacher, 1982), and it is relevant much more broadly in the perception and interpretation of many other phenomena in our natural environments (discussed in Rendall et al., 2007).

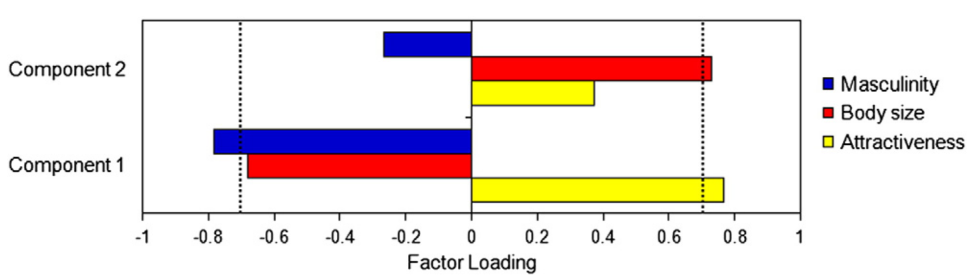

Fig. 7. PCA factor loadings for men's ratings of natural women's voices. Additional details as per Fig. 2.

Ultimately, conceptually linking voice-based assessments of masculinity or femininity and attractiveness to basic auditory perceptions of size could be highly functional—an effective cognitive heuristic—if it accurately captures the real-world associations between size and these other dimensions. In this respect, there is a natural and obvious association between size and the relative bassness of voices across age–sex classes, where men are larger than women, on average, and have lower-frequency voices in both F_0 and Fn; in turn, women are larger and have lower-frequency voices than adolescents and children (Lieberman & Blumstein, 1988). These natural sound–size associations across age–sex classes are familiar to everyone from a lifetime of social interaction. Hence, they might support and structure the kind of linking of mate-relevant dimensions observed. For example, men who are noted for consistent preferences for more youthful partners (where youth is hypothesized to be functionally associated with greater fertility and thus femininity; Buss, 1989; Buss & Schmitt, 1993; Symons, 1995) might naturally associate high-frequency voices with smaller size (relative youthfulness), femininity, and attractiveness. Similarly, women might naturally associate low-frequency voices with larger size and masculinity.

Studies that suggest real (rather than perceptual) interrelationships between body size (e.g., body mass index, muscle mass), masculinity or femininity (e.g., hormonal assays), and attractiveness might also be highlighting the value of a perceptual or cognitive heuristic that links these various dimensions (Bhasin et al., 1996, 1997; Boyapati et al., 2004; Collins, 2000; Collins & Missing, 2003; Evans et al., 2006; Jackson & McGill, 1996; Puts, Barndt, Welling, Dawood, & Burriss, 2011; Riding, Lonsdale, & Brown, 2006; Roney, Hanson, Durante, & Maestripieri, 2006; Thornhill & Gangestad, 1999; Yates, Edman, & Aruguete, 2004).

At the same time, it is also possible that the perceptual or conceptual linking of these mate-relevant dimensions is not actually functional if the dimensions being equated are not in fact strongly correlated with one another at the organizational levels that are most appropriate to the mate-choice problem, that is, within age–sex classes and not between them. Hence, it becomes critical to know, for example, whether the equating by women of body size and masculinity in assessments of men's voices is supported by a real correlation between adult body size and relative masculinity in men. Are larger men in fact more masculine? The same holds with respect to body size and relative femininity that were equated in men's assessments of women's voices. Are smaller women in fact more feminine? While there is evidence that circulating levels of testosterone (a potential index of masculinity) correlate with bone and muscle mass in men (Bhasin et al., 1996, 1997; Kung, 2003; Lorentzon, Swanson, Andersson, Mellström, & Ohlsson, 2005) and that circulating levels of estrogens (a potential index of femininity) correlate with body mass in women (Boyapati et al., 2004), circulating levels of these hormones do not accurately predict height in adults (Bruckert et al., 2006). Of course, if the effects of these hormones are most pronounced during puberty, then pubertal rather than adult hormone assays might offer more accurate assessments of masculinity, femininity, and ultimately adult size.

Furthermore, the relationships within sexes between either body size or masculinity/femininity and relevant voice characteristics (F_0 and Fn) are also not entirely clear, as noted in the Introduction. Hence, the functional basis for the equation of these different mate-relevant dimensions in voice-based assessments remains somewhat enigmatic. One possibility is that their equation arises naturally from an individual's lifetime experience and familiarity with the sound–size relationships that exist across age–sex classes, which might then influence listener's perception and interpretation of voice traits within age–sex classes where the relationships are, in reality, not so clear.

Future research would thus profit from additional specific tests of the relative independence of these (and other) mate-relevant dimensions that are traditionally used to assay and model the evolved structure of human vocal–perceptual systems. For example, social dominance is another trait potentially cued by voice F_0 and Fn that might provide further insight into the mechanisms that have shaped the human voice (Puts, Hodges, Cardenas, & Gaulin, 2007; Puts, Gaulin & Verdolini, 2006) and so should feature more in future investigation. Additional research is also needed on the related issues of how the basic personal dimensions being evaluated (body size, masculinity, and femininity) are causally related, if they are, and how they are then reliably manifest in specific voice traits (Fig. 1). Here, additional work is needed to resolve the connections between body size and masculinity or femininity and voice F_0 and Fn, in particular, but research on additional mate-relevant characteristics and voice traits would be valuable. For example, previous work that has highlighted the negative relationship between voice F_0 and testosterone in men (Dabbs & Mallinger, 1999), and thus F_0's indirect relationship to immunocompetence (Folstad & Karter, 1992; Thornhill & Gangestad, 1999), would benefit from specific tests of how reliably voice F_0 signals health and how perceptions of health correlate with other testosterone-dependent speaker dimensions, such as masculinity.

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