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Voice parameters predict sex-specific body morphology in men and women

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Studies of several mammalian species confirm that formant frequencies (vocal tract resonances) predict height and weight better than does fundamental frequency (F0, perceived as pitch) in same-sex adults due to differential anatomical constraints. However, our recent meta-analysis (Pisanski et al., 2014, *Animal Behaviour, 95*, 89–99) indicated that formants and F0 could explain no more than 10% and 2% of the variance in human height, respectively, controlling for sex and age. Here, we examined whether other voice parameters, many of which are affected by sex hormones, can indicate additional variance in human body size or shape, and whether these relationships differ between the sexes. Using a cross-cultural sample of 700 men and women, we examined relationships among 19 voice parameters (minimum–maximum F0, mean F0, F0 variability, formant-based vocal tract length estimates, shimmer, jitter, harmonics-to-noise ratio) and eight indices of body size or shape (height, weight, body mass index, hip, waist and chest circumferences, waist-to-hip ratio, chest-to-hip ratio). Our results confirm that formant measures explain the most variance in heights and weights of men and women, whereas shimmer, jitter and harmonics-to-noise ratio do not indicate height, weight or body mass index in either sex. In contrast, these perturbation and noise parameters, in addition to F0 range and variability, explained more variance in body shape than did formants or mean F0, particularly among men. Shimmer or jitter explained the most variance in men's hip circumferences (12%) and chest-to-hip ratios (6%), whereas harmonics-to-noise ratio and formants explained the most variance in women's waist-to-hip ratios (11%), and significantly more than in men's waist-to-hip ratios. Our study represents the most comprehensive analysis of vocal indicators of human body size to date and offers a foundation for future research examining the hormonal mechanisms of voice production in humans and perceptual playback experiments.

Many animals use vocalizations to communicate in social contexts. Vocalizations may communicate an animal's motivational state (Morton, 1977) but can also function as indexical cues to identity, sex and various physical traits (Ghazanfar & Rendall, 2008; Owren, 2011). Bioacoustic analyses suggest that the vocalizations of mammals contain reliable and perpetually salient information about a vocalizer's body size and mass (Ey, Pfefferle, & Fischer, 2007; Pisanski, Fraccaro, Tigue, O'Connor, Röder, et al., 2014; Taylor & Reby, 2010), and playback experiments suggest that both human and nonhuman listeners may use vocalizations to gauge the body size of conspecifics (e.g. humans, *Homo sapiens*: Charlton, Taylor, & Reby, 2013; Pisanski, Fraccaro, Tigue, O'Connor, & Feinberg, 2014; Rendall, Vokey, & Nemeth, 2007; Smith & Patterson, 2005; red deer, *Cervus elaphus*: Charlton, Reby, & McComb, 2007; koalas, *Phascolarctos cinereus*: Charlton, Whisson, & Reby, 2013; rhesus macques, *Macaca mulatta*: Fitch & Fritz, 2006; dogs, *Canis lupus familiaris*: Taylor, Reby, & McComb, 2010).

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Known Vocal Indicators of Body Size

Following the source-filter theory of speech production (Fant, 1960), researchers attempting to uncover which voice parameters may reliably indicate body size in humans and other mammals have focused on two largely independent features of the voice: mean fundamental frequency (F0, produced by vocal fold vibration and perceived as voice pitch) and formant frequencies (produced by filtering of the supralaryngeal vocal tract; Titze, 1994). Among humans, our recent meta-analysis showed that formants predict height and weight more reliably than does F0 when sex and age are controlled for (Pisanski, Fraccaro, Tigue, O'Connor, Röder, et al., 2014). This finding supports the prediction that mammalian formants are more anatomically constrained than is F0 (Fitch, 1994, 2000) and corroborates findings from several other mammalian species (reviewed in Kreiman & Sidtis, 2011). However, the meta-analysis also highlighted that formants could explain no more than 10% of the variance in men's heights, whereas mean F0 explained less than 2%. Formants accounted for even less of the variance in women's heights (6%), whereas mean F0 was not significantly correlated with height among women (Pisanski, Fraccaro, Tigue, O'Connor, Röder, et al., 2014). Because of the limited number of studies investigating other kinds of voice–body relationships, the meta-analysis did not test whether vocal features other than mean F0 or formants could explain additional variance in human body size, and did not examine relationships between the voice and body shape, such as circumference parameters.

Fundamental Frequency Range and Variability

A growing literature suggests that several voice parameters, in addition to formants and mean F0, may indicate body size and shape in one sex or the other. These voice parameters include non-mean-based measures of fundamental frequency such as minimum F0, maximum F0 and F0 variability (the standard deviation of F0, F0 SD) that are sexually dimorphic (Puts, Apicella, & Cardenas, 2012). These source measures indicate the upper and lower range of an individual's voice pitch and the degree to which voice pitch deviates from baseline across an utterance. The standard deviation of men's F0 appears to be a particularly reliable indicator of status, correlating negatively with self-reported dominance, reproductive success and testosterone level (Hodges-Simeon, Gaulin, & Puts, 2010, 2011). In a cross-cultural study, Puts, Apicella, et al. (2012) found that F0 SD predicted self-reported physical aggression in American men, and was marginally negatively related to arm strength among American but not Hadza men. In that study, however, formants reliably predicted height in both samples of men, whereas F0 SD did not.

Vocal Perturbation and Noise

Vocal frequency perturbation (jitter), amplitude perturbation (shimmer) and noise (harmonics-to-noise ratio) parameters may also correlate with body size or shape as they relate to the mass and oscillating properties of the vocal folds. Jitter and shimmer measure the mean deviation in voice pitch or amplitude between adjacent cycles, whereas harmonics-to-noise ratio measures the relative degree of periodicity to aperiodicity in the voice. A relatively high degree of jitter or shimmer or a low harmonics-to-noise ratio can indicate irregular vocal fold vibration, often caused by laryngeal asymmetry in mass or tension, which can result in vocal breathiness and hoarseness (Buder, 2000). Traditionally, these measures have been used by clinicians to assess voice quality in pathological voices (Maryn, Roy, De Bodt, Van Cauwenberge, & Corthals, 2009), however, several researchers have criticized the validity of jitter and shimmer as reliable indices of voice quality (Hillenbrand, 1987; Kreiman & Gerratt, 2005; Maryn et al., 2009).

Linders, Massa, Boersma, and Dejonckere (1995) suggested that jitter and body size may be negatively related to the extent that larger, more massive vocal folds may result in a mechanical dampening of vocal fold oscillation, producing a steadier voice pitch (see also Lieberman, 1963; Titze, 1988). However, vocal fold mass is more closely related to sex hormone levels than to height, where for example pubertal increases in testosterone masculinize and enlarge the vocal folds causing F0 to drop (Hollien, Green, & Massey, 1994; Prelevic, 2013). Indeed, researchers have long proposed that sex hormones may influence voice perturbation and noise parameters, either by affecting the mass of the vocal folds, or the motor and sensory processes involved in laryngeal control (e.g. Higgins & Saxman, 1989; Silverman & Zimmer, 1978; for more recent work see Gugatschka et al., 2010; Prelevic, 2013). It follows that jitter, shimmer and harmonics-to-noise ratio may relate to body size and in particular body shape via the shared influence of sex hormones on these vocal properties and on the development and distribution of fat and muscle on the body.

Relationships between perturbation or noise parameters and the human body have been examined in only a small number of studies with mixed results. González (2007) found that jitter correlated positively with women's body mass, such that heavier women showed more irregularities in their voice pitch, whereas shimmer and harmonics-to-noise ratio were relatively poor indicators of women's, and even less so of men's, heights and weights. In contrast, Linders et al. (1995) reported a negative correlation between jitter and height in prepubescent girls and boys independent of gender, suggesting that before puberty, shorter children show more irregularities in their voice pitch than do taller children. Finally, Hamdan et al. (2012) failed to find relationships between body size and jitter or harmonics-to-noise ratio, but reported weak positive relationships between shimmer and trunk fat or muscle mass in men. The largest same-sex sample among these studies included only 81 individuals (González, 2007), which may be too few to detect various voice–body relationships.

Vocal Indicators of Body Shape?

There is some evidence that information about body shape, not only height and weight, may be present in the human voice. The principal mechanism linking voice to body shape may be hormonal (Hughes & Gallup, 2008). In addition to affecting voice F0 and formants, and possibly also perturbation parameters (Abitbol, Abitbol, & Abitbol, 1999; Dabbs & Mallinger, 1999; Lieberman, McCarthy, Hiiemae, & Palmer, 2001), oestrogens and androgens affect the circumferences of the waist, hips and chest and the ratios among them (waist-to-hip ratio, chest-to-hip ratio), as well as an individual's body mass index (Blouin, Boivin, & Tchernof, 2008; Derby, Zilber, Brambilla, Morales, & McKinlay, 2006; Evans, Hoffmann, Kalkhoff, & Kissebah, 1983). These indices of body shape are sexually dimorphic and can vary independently of one another within the same individual. Moreover, the distribution of fat and muscle mass on the body that determines body shape is largely independent of the amount of fat and muscle on the body that determines body mass (Singh & Singh, 2011).

Similar to physical height, indices of body shape such as waist-to-hip ratio and chest-to-hip ratio can provide socially relevant information about an individual (Hughes & Gallup, 2008). For instance, body shape predicts a wide range of health-related factors in both sexes, controlling for body mass (Blouin et al., 2008; Larsson et al., 1984; Seidell, 2009). Among women, waist-to-hip ratio and the body mass index are robust predictors of fecundity and correlate with ratings of women's physical attractiveness from