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# Voice pitch: a window into the communication of social power

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Pitch is the most perceptually salient acoustic property of the voice and influences perceptions of characteristics related to social power, such as dominance and leadership abilities. Voice pitch is also highly sexually differentiated; men vocalize approximately one octave below women. We consider the evolution of this sex difference, and how this sheds light on the human tendency to defer to individuals with lower voice pitch. We present new meta-analyses linking lower pitch to higher testosterone (total $n = 763$) and upper-body strength (total $n = 845$) and review other recent evidence linking voice pitch to power. We find that these relationships are typically modest and consider why voice pitch has comparatively larger effects on power-related perceptions, such as perceived size and dominance, in laboratory studies. Although more data are needed, we conclude that voice pitch is likely to be an honest signal associated with success in status and contest competition.

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## Introduction

Pitch is the most perceptually salient acoustic property of the voice [1] and is intimately connected to *social power* – that is, control over others' valued outcomes [2]. Yet, the various ways by which voice pitch influences, and is influenced by, social interactions are frequently outside our conscious awareness. Studying these relationships thus offers a unique window into how social power is communicated, as well as shedding light on key aspects of human evolution – in particular, those related to competition for status and mates.

We examine how voice pitch influences perceptions of the speaker's power and explore the social and reproductive consequences. Next, we consider how these processes may have influenced the evolution of low voice pitch in males of many primate species, including humans. Finally, we consider why we defer to individuals with lower voice pitch. We evaluate the recent idea that low male pitch is a purely deceptive exaggeration of size [3•] and review evidence for the alternative hypothesis that pitch honestly signals status, formidability, and/or underlying condition.

## Power and voice pitch

Voice pitch is determined primarily by the vibratory rate of the *vocal folds*: skeletal muscle covered by the gel-like lamina propria and epithelium, stretched anteroposteriorly across the larynx. During phonation, air forced between the bilaterally paired vocal folds causes them to vibrate. Longer vocal folds with less muscular tension on them vibrate at a lower fundamental frequency ($f_o$), which we perceive as lower pitch [1]. In males, the pubertal rise in testosterone causes the vocal folds to hypertrophy and for $f_o$ to drop [4–6]. Consequently, compared to women, men have approximately 60% longer vocal folds and an $f_o$ that is five standard deviations lower [7].

Fundamental frequency influences a variety of perceptions related to a speaker's power. In experimental and correlational research, lower $f_o$ conveys the impression that the vocalizer is larger, older, more masculine, and more physically and socially dominant [8–14]. In an experimental study with a nationally representative sample of American adults, both men and women preferred voting for male and female political candidates with lower $f_o$ [15]. Another study revealed that even in the context of leadership positions that are usually held by women (e.g. president of a school-level voluntary service organization), both male and female leaders with lower $f_o$ were preferred [16].

A growing body of work suggests that these perceptual effects have real-world consequences. Studies have tended to focus on men, perhaps because low $f_o$ is a male secondary sex trait. Among hunter-gatherers, lower male $f_o$ predicted increased reproductive success [17] and greater hunting reputation [18]. In Western populations, men with lower $f_o$ report more sex partners [11], oversee larger business firms and obtain longer tenures [19], and achieve greater political power [13,16]. For example, male candidates with lower $f_o$ won a larger vote share than their male opponents in the 2012 U.S. House of Representatives elections [15].

## Sexual selection and sexual dimorphism in $f_o$

Many of these observations were predicted from the idea that human voice pitch has been shaped by sexual

selection, the type of natural selection engendered by competition for mates. In most animal species, including humans, the ability to acquire mates is more strongly linked to male reproductive success than female reproductive success [20]. In these species, males therefore tend to experience stronger sexual selection and possess traits that function in winning mates. In many anthropoid primates, low-frequency vocalizations and associated vocal anatomy may have helped ancestral males obtain mates by intimidating other males and/or attracting females [7,21], leading males to evolve relatively low $f_o$.

Sexual dimorphism in $f_o$ appears to be ancient, probably arising in the common ancestor of the catarrhines (Old World monkeys and apes) after their divergence from the New World monkeys [7] approximately 43.5mya [22], and to have subsequently been elaborated or reduced depending on the form and degree of male mating competition [7]. For example, $f_o$ dimorphism reaches extremes in polygynous *Cercopithecus* monkeys, whereas it has been lost in the socially monogamous lesser apes. In the lineage leading to humans, phylogenetic reconstruction indicates that $f_o$ dimorphism increased from the common ancestor of the apes onward, culminating in modern humans having the greatest $f_o$ dimorphism of any extant ape [7].

Like other male secondary sex traits, including facial hair and muscularity, men's $f_o$ shows evidence of having been shaped primarily by intrasexual competition between males [11,23,24,25•,26]. For example, $f_o$ functions more effectively at conveying impressions of formidability to other men than it does at attracting women [11,12,23,26], although female mate choice likely favored low male $f_o$ as well [11,12,21]. It is also possible that male mate choice favored the retention of high, youthful-sounding $f_o$ into adulthood in women [10,27]; however, $f_o$ has been found to predict reproductive success [17] and components of mating success [7] in men but not women [cf 28], and cross-species data indicate that sexual dimorphism in $f_o$ evolves when mating competition is more intense among males in particular [7].

Low male $f_o$ may exert its influence by exaggerating the appearance of size [29], and may have evolved for this function [7]. Following the basic physical association between large objects or events and the low-frequency sounds they produce, there is a corresponding tendency for listeners to link low with large [29]. Although this tendency has been referred to as a 'sensory' bias [3•], we note that the human auditory system is not in fact attuned to male frequencies — we hear higher frequencies better for a given amplitude [30] — hence, *perceptual* bias may be more apt. Nevertheless, a deep $f_o$ appears likely to have evolved in Old World monkeys and apes to exploit a preexisting perceptual association of low frequencies with large sound sources.

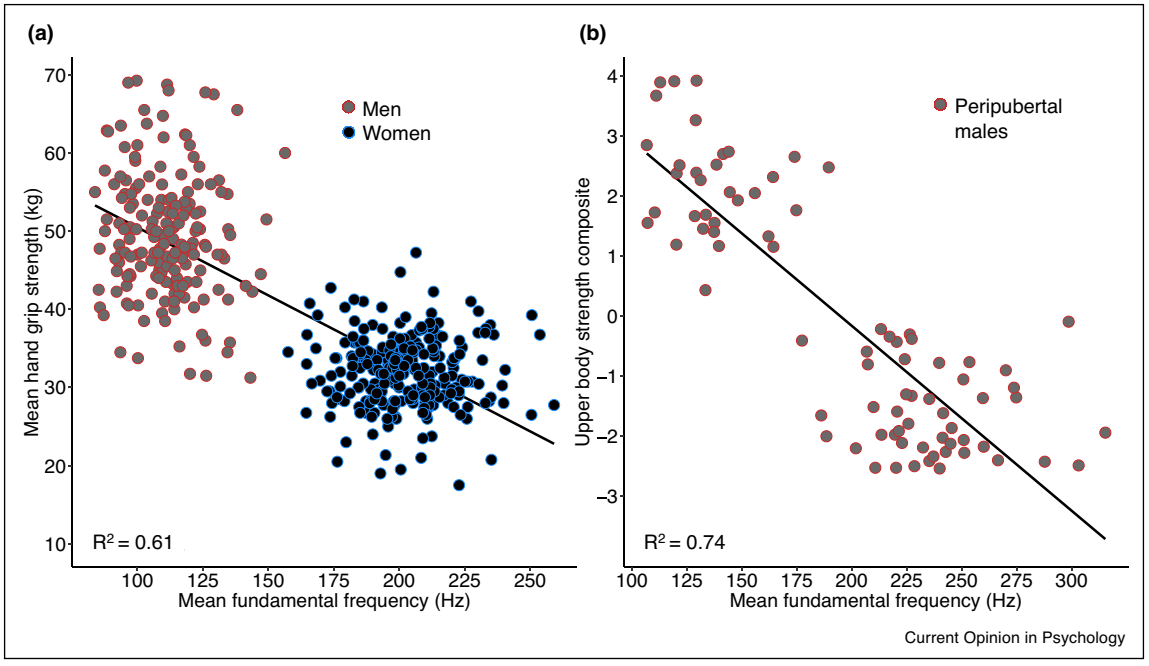
According to perceptual (and sensory) exploitation hypotheses, sensitivity to a male trait existed before the trait evolved [31], but these hypotheses do not speak to whether the trait actually provides information about its bearer. Thus, a perceptual exploitation hypothesis for low male $f_o$ would postulate that attention to $f_o$ did not evolve *because* male $f_o$ provides information, as would some other sexual selection models. Following this logic, some authors have suggested that, within men, $f_o$ does not indicate threat potential or condition and is purely deceptive [3•,32,33]. While this is possible, game-theory models suggest that deceptive signaling must be infrequent for the signaling system to be evolutionarily stable [34]. If the trait provides no relevant information about its bearer, then selection should favor decreased sensitivity to the trait. Thus, if men's $f_o$ is unrelated to social and/or physical power, then the loss of status, mating, and reproduction incurred by deference to individuals with low $f_o$ should favor relative inattention to men's $f_o$ [35•]. Yet, people are highly sensitive to men's pitch, as noted above. Likewise, in one of the best characterized examples of sensory exploitation, male túngara frogs seemingly evolved low frequency calls to leverage a preexisting female preference, but the preference was probably maintained in part because male calls provide important information: males with deeper calls are larger and leave fewer eggs unfertilized [36].

## Is $f_o$ an honest signal?

The forgoing discussion highlights one of the most interesting unresolved questions surrounding the human voice: what information does voice pitch convey? Because of the strong associations between $f_o$ and both sex and male physical maturation, $f_o$ provides abundant information about components of power, for example, explaining over 60% of the variation in physical strength in a sample of young men and women (Figure 1a) and over 70% of the variation in upper-body strength among peripubertal male Amazonian forager-horticulturists (Figure 1b). Thus, attention to $f_o$ may be maintained in part because $f_o$ conveys information about sex and male physical maturity, and hence sex-related and age-related variables such as size, strength, and social influence [29]. Likewise, attention to $f_o$ could in part reflect adaptation to broader sound-size associations in the natural world (e.g. large versus small fauna, waterfalls, falling trees; [29]). However, the tendency for listeners to discriminate variation in $f_o$ within men, coupled with the apparent status, mating, and reproductive consequences, suggests that $f_o$ provides information about power within men, as well. Several lines of evidence support this inference.

For example, male $f_o$ is influenced by steroid hormones. Testosterone reflects nutritional state and body condition [37,38], as well as aggression, status, and status-related behaviors [39,40]. Male $f_o$ is strongly linked to testosterone across the time window surrounding puberty [41], and meta-analysis

**Figure 1**




Following its steep drop at puberty in males, $f_o$ is highly sexually dimorphic in adulthood (Cohen's $d \approx 5$). Consequently, $f_o$ provides information about sex and physical maturation, and hence about related variables such as strength. For example, $f_o$ explained **(a)** over 60% of the variance in hand strength in a mixed-sex sample of young adult U.S. university students (data from Ref. [7]), and **(b)** over 70% of the variance in upper-body strength among Bolivian forager-horticulturist males, ages 10–23 (data from [67]; two men ages 22.1 and 19.4 removed due to $f_o$ values approximately 4 and 5 SD, respectively, above the adult male mean [40]).

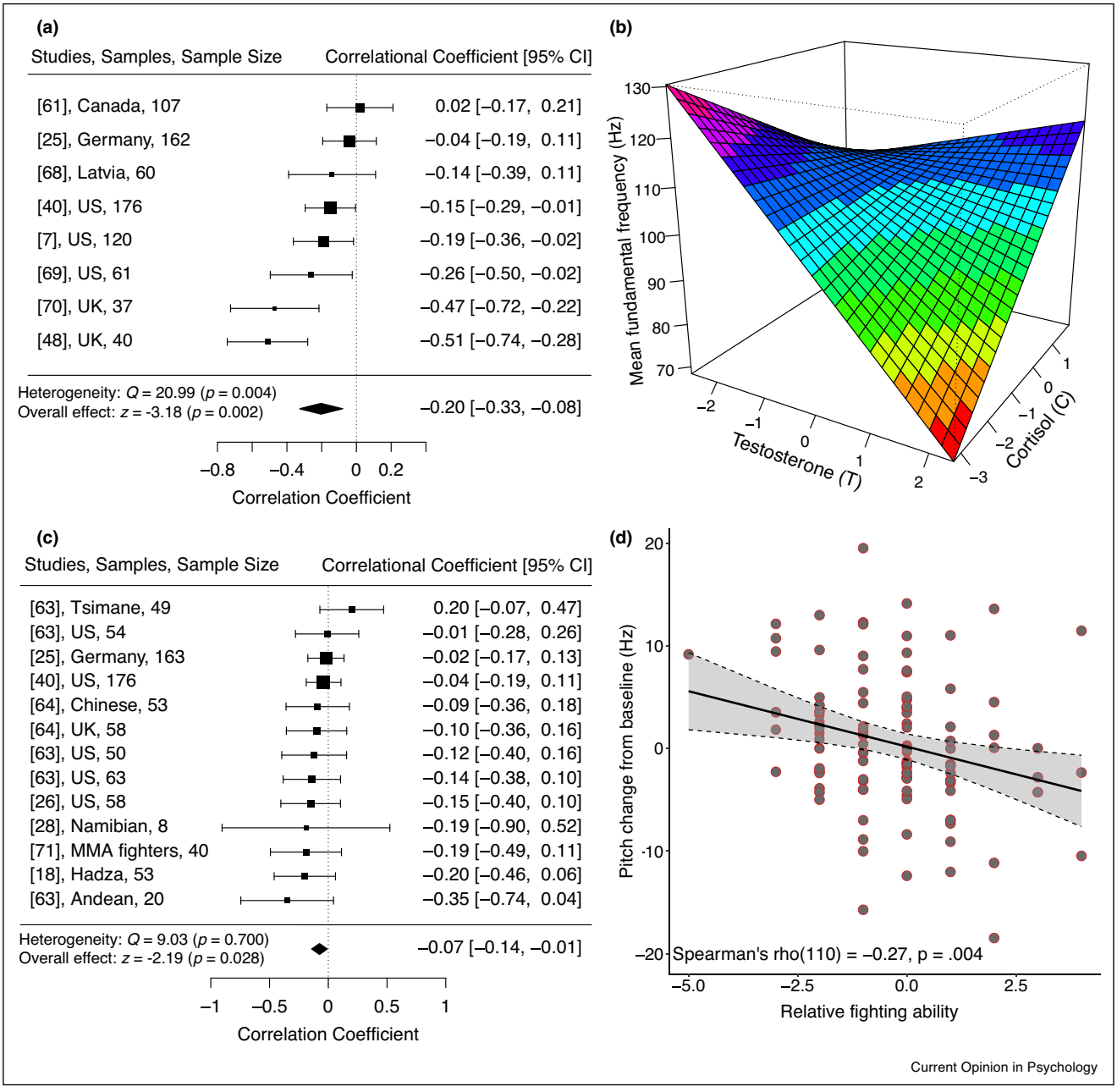
of eight published studies (total $n = 763$) indicates that higher testosterone predicts lower $f_o$ in adulthood as well (Figure 2a). Testosterone also more strongly predicted $f_o$ in individuals with lower cortisol levels in two samples of U.S. men, but not in women [7; see also Figure 2b]. Although the relationships are likely complex, cortisol has been linked to infection and other physiological stressors [42], may inhibit testosterone action on target tissues [43,44], and has been found to negatively interact with testosterone in predicting both status-related behaviors in humans [39] and immune function in both humans [45] and nonhuman vertebrates [46,47].

Lower $f_o$ in men has also been found to predict anthropometric measurements related to formidability and condition, including greater shoulder and chest circumference in a British sample [48] and height in a meta-analysis across 39 samples comprising 1119 men [49]. Because height reflects good nutrition and low developmental stress [50,51], as well as genetic predictors of immune function [52], this suggests that $f_o$ reflects underlying ondition as well. Lower $f_o$ also weakly predicted greater upper-body strength in our meta-analysis of eight published studies (total $n = 845$; Figure 2c).

Signal honesty can be assessed by measuring costs. If costs increase with the value of the signal, then this suggests that individuals producing higher-value signals can bear greater costs. In a recent study [53••], low-$f_o$ male voices elicited aggressive cognitions and intent from men who perceived themselves to be more dominant and stronger, suggesting substantial social costs to falsely signaling dominance through low $f_o$. The notion that a low $f_o$ imposes social costs is further supported by studies showing that men tend to raise their $f_o$ when speaking to more dominant or prestigious competitors and lower it when they perceive themselves to be more dominant or prestigious [12,54•; Figure 2d]. In other words, men seem to adjust $f_o$ to the costs of asserting power. Intra-individual changes in $f_o$ are mediated by muscular tension on the vocal folds, giving $f_o$ considerable flexibility to signal condition, status, or dominance strategically. Indeed, evidence suggests that both men and women modulate voice pitch across social contexts in relation to such factors as relative formidability [12,54•,55], authority [56•], and romantic interest [57,58].

These and other lines of evidence suggest that $f_o$ predicts power within men. Each of the above measures is a proxy for underlying condition, or represents only one of many components of power. Consequently, evaluating condition or power with more precise measures or across multiple measures may produce stronger relationships

**Figure 2**




Some evidence that $f_o$ signals condition. **(a)** Meta-analysis of correlations between men's $f_o$ and testosterone levels across published studies, using a random effects model. **(b)** Negative interaction between testosterone and cortisol in predicting men's $f_o$ (combines data from both studies in [7]). **(c)** Meta-analysis of correlations between men's $f_o$ and upper-body strength across published studies. We used a random slope model where samples are allowed to have different slopes for the effect of upper-body strength measurement types across studies. **(d)** Male $f_o$ changes in relation to the vocalizer's perceived dominance [12]. Note: Panel b was plotted via 'rsm' package [62], and meta-analyses were conducted via 'metafor' package [65] in R statistical software [66]. More information on how studies [7,18,25,26,28,40,48,61,63,64,68–71] were included in our meta-analyses can be found online at https://osf.io/4ymzf/.

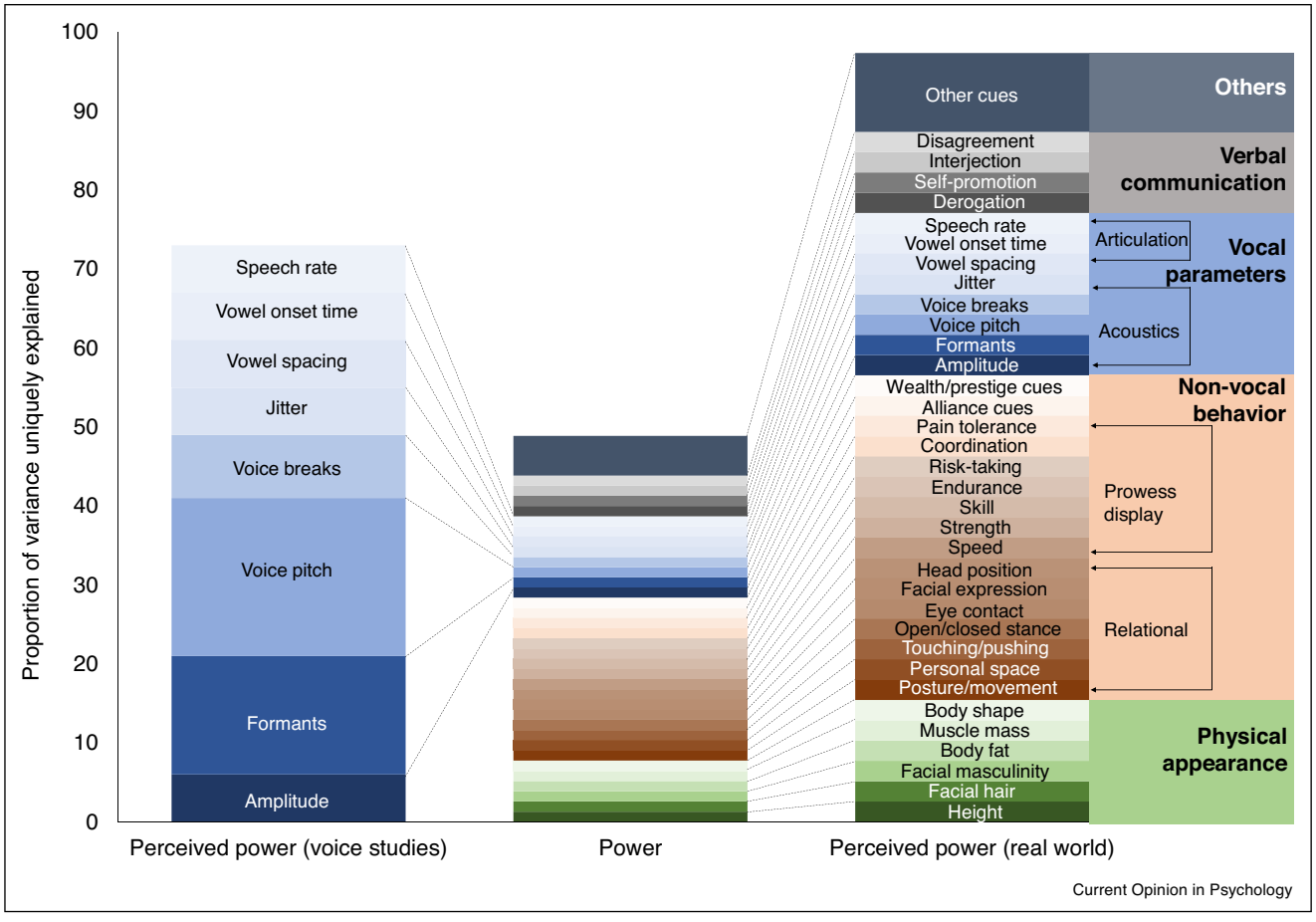
with $f_o$. However, many of these relationships are modest (correlations in the 0.1–0.4 range), raising the question of why they are considerably weaker than the effects of men's $f_o$ on perceptions of size, dominance, and the like observed in laboratory studies (correlations in the 0.3–0.7 range [7,32]). Given its perceptual salience, why is $f_o$ not a more precise cue of power within men?

In most animals [59], including humans [60], signaling is multimodal and involves multiple components within

sensory modalities. Multiple signaling and sensitivity to multiple cues can evolve for a variety of reasons, including enhanced information content from non-redundant signal components; compensation for error during information coding of individual signals; emergence of information from signal integration; improved signal detection; as well as differential signal information content or transmission across environments [59]. Laboratory studies that ask participants to evaluate size, dominance, and so forth from highly standardized vocal stimuli thus omit many signals and cues that are normally available and therefore both (a) present a paucity of information from which to make these evaluations, and (b) artificially inflate the salience of the information presented. For example, when participants were presented only with standardized sequences of vowel sounds and asked to estimate height [32], $f_o$ and other salient acoustic correlates of size predictably played large roles in these estimations, and height estimations were unsurprisingly imprecise.

Outside of such artificial settings, people form impressions from numerous other cues, including aspects of physical appearance, behavior, and many other acoustic and linguistic variables (Figure 3). In combination, multiple cues provide more information, and individually, each cue will uniquely explain only a portion of the variance in both condition and relevant perceptions. Where dominance has been assessed in more information-rich contexts — ratings of video stimuli or

**Figure 3**




Hypothetical correlations between cues and both power and perceptions of power. Artificially large perceptual effects can be produced in laboratory studies where participants make judgments from highly standardized vocal stimuli alone (left column). In the real world, where signaling is multimodal and multicomponent, impressions are formed from numerous other cues, including aspects of physical appearance, behavior, and many other acoustic and linguistic variables (right column). Because there is noise in any informational system, and because biological signals will have additional noise due to deception, the proportion of variance in *actual* power uniquely explained by each cue (middle column) should be somewhat less than the variance it explains in *perceptions* of power. Note: For clarity and simplicity, all cues are shown as explaining equal variance in power in the middle and right columns. However, because natural selection will favor stronger attention to cues that more precisely index power, the effects of cues on *perceptions* of power should tend to be proportional to the cues' correlations with *objective measures* of power.

evaluations made by familiar peers — $f_o$ explained around 3–4% of the variance in dominance ratings, and no measured cue explained more than 8% of the variance [25•,26]. Associations between cues and perceptions will generally be stronger than the associations between cues and condition (Figure 3). Because there is noise (if not also deception) in any signaling system, observers will always form judgements from partial information. Hence, if $f_o$ explains approximately 3–4% of the variance in dominance perceptions in naturalistic contexts, then it should explain somewhat less of the variance in objectively measured dominance.

These modest associations between $f_o$ and perceived power in more ecologically valid contexts accord better with links between $f_o$ and objective measures of power and condition reviewed above. This does not imply that $f_o$ is unimportant as a cue of power, but rather that there are many important cues. It also suggests that the apparent mismatch between perceptions and reality may be largely artifactual.

## Conclusions

Voice pitch, measured by $f_o$, strongly influences perceptions related to power in controlled laboratory studies and modestly predicts these perceptions in information-rich naturalistic contexts. These perceptual effects appear to have real-world consequences in terms of social status, leadership, mating, and reproductive success. Ancestral male catarrhine primates appear to have leveraged a perceptual association of low $f_o$ with size to exaggerate their own apparent size to competitors and potential mates. Sex differences in $f_o$ were lost in socially monogamous catarrhines such as gibbons and elaborated in species with more intense male mating competition, including *Cercopithecus* species and humans. An important unresolved question is why, in humans, competitors continue to cede status, resources, and mating opportunities to men with low $f_o$. Such deference is particularly perplexing if, as has recently been suggested, $f_o$ is a purely deceptive signal. Although the hypothesis that $f_o$ is purely deceptive is theoretically implausible and inconsistent with the data reviewed above, it is possible that within-sex perceptual effects could be maintained in part by overgeneralization of sound-size correlations across sexes and stages of physical maturity, as well as within the natural world more broadly [29]. Some evidence also indicates that $f_o$ is a valid signal of qualities associated with success in status and contest competition, and that correlations between these qualities and $f_o$ are of theoretically expected magnitudes.

Future research should continue to investigate the strength and direction of associations between $f_o$ and measures of social power, formidability, and condition, such as immune function [41,61•], across populations, as well as cross-cultural variability in the perceptual influence of $f_o$. In addition, because low voice pitch is a secondary sex trait in men and is likely to have been the product of sexual selection in males, relationships between voice pitch and power have understandably been studied mainly in this context. Yet, available evidence reviewed above suggests that pitch is also highly salient in perceptions of women's voices [56•], and more work is needed in this area.

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