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Listen, Follow Me: Dynamic Vocal Signals of Dominance Predict Emergent Social Rank in Humans

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Similar to the nonverbal signals shown by many nonhuman animals during aggressive conflicts, humans display a broad range of behavioral signals to advertise and augment their apparent size, strength, and fighting prowess when competing for social dominance. Favored by natural selection, these signals communicate the displayer's capacity and willingness to inflict harm, and increase responders' likelihood of detecting and establishing a rank asymmetry, and thus avoiding costly physical conflicts. Included among this suite of adaptations are vocal changes, which occur in a wide range of nonhuman animals (e.g., chimpanzees, rhesus monkeys) prior to aggression, but have not been systematically examined in humans. The present research tests whether and how humans use vocal pitch modulations to communicate information about their intention to dominate or submit. Results from Study 1 demonstrate that in the context of face-to-face group interactions, individuals spontaneously alter their vocal pitch in a manner consistent with rank signaling. Raising one's pitch early in the course of an interaction predicted lower emergent rank, whereas deepening one's pitch predicted higher emergent rank. Results from Study 2 provide causal evidence that these vocal shifts influence perceptions of rank and formidability. Together, findings suggest that humans use transient vocal changes to track, signal, and coordinate status relationships.

Keywords: dominance, social hierarchy, vocal pitch, nonverbal behavior, signaling

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Although coordination and affiliation form the primary fabric of social life among many species, group living necessarily results in conflicts over divergent goals, and zero-sum competitions for valued resources. To tackle this recurrent problem, many species have evolved psychological and behavioral adaptations that facilitate the formation and maintenance of rank asymmetries (Schjelderup-Ebbe, 1922; Lorenz, 1966; Mazur, 1985; Brown, 1991). The resultant status hierarchies establish a mutually accepted agreement on the differential priority and access to contested resources, and thereby enable stable patterns of social exchange, prevent costly fights, and, in consequence, maximize individual fitness (Christian, 1970; Smith & Parker, 1976; Smith & Price, 1973; Parker, 1974). Indeed, a large body of evidence indicates that hierarchical stratification organizes many everyday social exchanges and facilitates group coordination. In humans, relative social rank reliably predicts patterns of dominance–submission (i.e., influence, deference, attention; Chance, 1967; Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013; Fournier, Moskowitz, & Zuroff, 2002; Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011; Tiedens & Fragale, 2003), distribution of wealth (Hawley, 2002; Sidanius & Pratto, 1999), health (Adler et al., 1994), access to mates (Buss, 1989), and reproductive success (von Rueden, Gurven, & Kaplan, 2011). Equally important, stable hierarchical systems enhance group-wide motivation, cooperation, and productivity (Anicich, Swaab, & Galinsky, 2015; Bendersky & Hays, 2012; Halevy, Chou, Galinsky, & Murnighan, 2012; Ronay, Greenaway, Anicich, & Galinsky, 2012; Tiedens & Fragale, 2003).

The substantial advantages conferred by social rank asymmetries—combined with evidence of spontaneous, rapid, and reliable emergence of hierarchical relationships within human social groups across a broad range of environments (Bass, 1954; Kalma, 1991; Lee, 1979; Lewis, 1974)—lead to the expectation that our species be equipped with psychological and behavioral adaptations designed to facilitate the signaling and detection of relative rank differences. In fact, several externally visible features of human morphology, including height, muscularity, and facial structure, reliably track and signal fighting ability, and are used to assess formidability (Carré & McCormick, 2008; Fessler, Holbrook, & Snyder, 2012; Judge & Cable, 2004; Puts, Gaulin, & Verdolini, 2006; Sell et al., 2009, 2010).

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However, these stable features have several limitations. For example, when disparities in size and strength are not readily apparent (Parker, 1974), or contestants' ability to inflict harm is heavily influenced by ecology-specific factors—including availability of allies, existing injuries, differences in age and overall physiological condition, territorial ownership and experience, or (in humans) differential access to weapons, and disparate wealth and resources that correlate with fighting ability—these relatively immutable morphological features become inadequate for signaling an individual's current competitive intentions. As a result, natural selection should also favor the emergence of more dynamic behavioral displays to flexibly advertise size-independent rank-attainment motivations. These displays, in conjunction with stable morphological features, would provide a summary assessment of individuals' relative formidability under current ecological conditions (Bro-Jørgensen, 2010; Otte, 1974; Tinbergen, 1959). Consistent with this reasoning, as well as observations made of other primates (de Waal, 1982; de Waal & Luttrell, 1985), a growing body of evidence indicates that humans rely on dynamic momentary behavioral displays to communicate and exchange information about formidability and competitive or submissive intentions. Among the most visually detectible are postural expansion versus constriction (Dovidio, Ellyson, Keating, Heltman, & Brown, 1988; Shariff & Tracy, 2009; Tiedens & Fragale, 2003), emotion expressions of pride, anger, and contempt versus fear, shame, and sadness (Fournier, 2009; Keltner, Gruenfeld, & Anderson, 2003; Marsh, Cardinale, Chentsova-Dutton, Grossman, & Krumpos, 2014; Shariff, Tracy, & Markusoff, 2012; Tracy, Shariff, Zhao, & Henrich, 2013), and sustained eye gaze versus gaze aversion (Dovidio et al., 1988).

Despite the importance of these visually detectible signals, there are occasions when even these more dynamic cues would be ineffective, due to distance, darkness, or obscuration (Sell et al., 2010). These limitations may have favored the emergence of supplemental signaling systems that do not rely on sight, such as vocal signals. Indeed, several lines of research indicate that individual differences in habitual vocal pitch—the perceptual parameter that corresponds to vocal fundamental frequency, and the most perceptually salient aspect of the human voice (Banse & Scherer, 1996)—are consistently linked to rank-attainment motivations and outcomes in humans. First, a deeper voices convey a speaker's increased threat potential, by virtue of their reliable association with stable characteristics related to threat, including physical size and upper-body strength (Bruckert, Liénard, Lacroix, Kreutzer, & Leboucher, 2006; Evans, Neave, & Wakelin, 2006; Hodges-Simeon, Gurven, Puts, & Gaulin, 2014; Puts, Apicella, & Cárdenas, 2012), endogenous circulating testosterone (Bruckert et al., 2006; Dabbs & Mallinger, 1999; Evans, Neave, Wakelin, & Hamilton, 2008; Puts et al., 2012), and exposure to testosterone during development (Harries, Hawkins, Hacking, & Hughes, 1998). Studies have found that increases in testosterone, such as those resulting from experimental administrations, leads to heightened status-seeking motivations, increased social vigilance, and reductions in fear and stress (see Eisenegger, Haushofer, & Fehr, 2011). Thus, a deepening voice may cue that an individual is psychologically and physiologically ready for a status competition.

Second, experimental studies have found that lower pitched voices are widely perceived as indicating greater size, strength, dominance, and leadership capacity (Feinberg, Jones, Little, Burt, & Perrett, 2005; Gregory, Dagan, & Webster, 1997; Gregory, Green, Carrothers, Dagan, & Webster, 2001; Klofstad, Anderson, & Peters, 2012; Puts et al., 2006; Puts, Hodges, Cárdenas, & Gaulin, 2007; Tigue, Borak, O'Connor, Schandl, & Feinberg, 2012; Wolff & Puts, 2010); but see Ko, Sadler, & Galinsky, 2015). These findings, along with evidence of a similar association between the pitch of acoustic signals and fighting ability in many other species (Gerhardt, 1994), suggest that individual differences in habitual vocal pitch may provide cues about the stable fighting ability or propensity of the vocalist.

Dynamic changes in vocal pitch, however, have received far less empirical attention, compared to stable individual differences in habitual pitch frequency (Puts et al., 2006; Scherer, 1986). Comparative studies, however, have documented the pervasiveness of dynamically altered acoustic signals across the animal kingdom. Frogs, for example, lower the pitch of their calls during aggressive encounters, particularly under environmental conditions where it would be especially advantageous to exaggerate one's size (e.g., to deter intruders; Bee, Perrill, & Owen, 1999, 2000), and these deepening pitch calls are more effective at deterring challengers than calls that either increase or do not change in pitch frequency (Wagner, 1992). Similarly, both rhesus monkeys and chimpanzees produce acoustically distinct vocalizations depending on the relative rank of the opponent with whom they are fighting and the ally whose help they are seeking (Gouzoules, Gouzoules, & Marler, 1984; Morton, 1977; Slocombe & Zuberbühler, 2007).

These patterns found in the natural world converge with one of few relevant studies examining pitch change in humans, which found that men may systematically use pitch modulations to signal dominance. Specifically, Puts and colleagues (2006) found that, when addressing an ostensible rival, men who consider themselves to be physically stronger lower their vocal pitch, whereas men who consider themselves to be physically weaker raise their pitch. This finding is consistent with results from several studies examining pitch modulations in naturalistic interactions, which demonstrate that the lower-status counterpart in an interaction shows asymmetrically greater variation in pitch, in an effort to accommodate the person of higher status (Gregory et al., 2001; Gregory & Webster, 1996). This research, along with studies linking stable individual differences in vocal pitch to social rank in humans, raise the possibility that similar pitch alteration signals may function to effectively communicate the intention to dominate or submit in our species. If this is the case, systematic patterns of pitch alteration that occur during human rank contests may influence the outcome of these disputes and shape subsequent rank asymmetries. Although these studies tentatively suggest the presence of systematic pitch alterations in human rank competitions, it remains to be determined whether and how these shifts in pitch influence perceptions of the signaler's dominance motivations, and whether they shape resultant rank asymmetries.

To examine this issue, we tested whether people spontaneously show dynamic changes in their vocal pitch during a rank contest, and how these emitted cues shape the subsequently emerging social hierarchy. We predicted that a dynamically deepening pitch profile communicates an individual's motivation to dominate, and, as a result, would be associated with higher emergent rank. Conversely, we expected a rising pitch profile to communicate the willingness to submit, and thus be associated with lower emergent rank. Furthermore, because pitch modulations are expected to shape rank outcomes primarily by augmenting or diminishing one's apparent physical size, motivation to engage in conflict, and formidability—given the widespread tendency to ascribe greater size and strength to deeper voices (Feinberg, Jones, Little, et al., 2005; Puts et al., 2006)—pitch modulation should be associated with perceptions of dominance—a rank-attainment strategy based on threat of force and intimidation (Cheng et al., 2013; Cheng, Tracy, & Henrich, 2010; Henrich & Gil-White, 2001). We further expected that the rank consequences of pitch alterations would *not* be attributable to prestige—an alternative rank attainment strategy based on earned respect and the demonstration of skills or expertise. In light of experimental evidence indicating that the perceptual association between deeper vocal pitch and dominance applies to both male and female voices (Borkowska & Pawlowski, 2011; Jones, Feinberg, DeBruine, Little, & Vukovic, 2010), we expected these predictions to hold across gender (notably, testosterone surges have been shown to have similar effects in men and women).

We tested these predictions in two studies. Study 1 sought to establish the presence of rank-related pitch alterations in a real-world context by assessing naturally occurring vocal changes during the process of hierarchy formation in small groups. Study 2 complemented this ecologically valid approach by manipulating pitch alterations via a playback paradigm, and testing whether these shifts influence listeners' perceptions of rank-seeking intentions and dominance.

Study 1: Pitch Alterations and Rank Attainment in Face-to-Face Social Interactions

Study 1 tracked naturally occurring dynamic changes in pitch during face-to-face interactions among individuals assigned to work together on a problem-solving task. We tested whether vocal changes that spontaneously occurred during the first moments of these interactions predicted individuals' likelihood of prevailing or submitting in the group, as well as perceptions of formidability.

Method

Participants. One hundred, 91 students (54% male), ranging in age from 17 to 52 ($M = 23.01$, $SD = 6.08$), at a large Canadian university participated for monetary compensation. Participants were randomly assigned to one of 36 same-sex groups that ranged in size from four to seven individuals ($M = 5.34$, $SD = .83$). No group members were previously acquainted.

Procedure. The study began with participants completing a decision-making task privately. They then worked collectively with their group for 20 min on the same task. They were instructed to use their previously completed private responses to guide these group discussions. The task, known as "Lost on the Moon" (Bottger, 1984), involves rank-ordering 15 items (e.g., oxygen tanks, heating unit) according to their perceived utility for surviving a disaster on the moon. The group component was video-recorded. Participants' task engagement was incentivized via the instruction that every member of high-performing groups would receive a $5 bonus, in addition to their $10 compensation for participation. In actuality, all participants received this monetary bonus. After the group task, participants privately rated the social rank and formidability, a trait central to dominance (Henrich & Gil-White, 2001), of each group member.

Measures.

Vocal pitch. An audio track was created for each group session from the video-recording, and saved as an uncompressed "wave" file with 44.1 kHz sampling rate and 16-bit quantization. We examined participants' spontaneous speech in the initial minutes of the group task by sampling each participant's first three utterances, which were spoken, on average, at 3.28, 4.32, and 5.98 min into the 20-min collaborative component. We focused on these initial utterances to track changes in pitch that occurred largely before rank asymmetries were established. Furthermore, prior work suggests that dominance signals are likely to be especially pronounced and readily attended to early on in a social interaction, before asymmetries are determined (Curhan & Pentland, 2007; Mazur, 1985).

An utterance was defined as uninterrupted speech lasting 40-ms or longer. This short time frame was adopted because, in these naturalistic interactions, many participants made only brief comments (e.g., *okay*, *sure*), particularly at the beginning of the task. The fundamental frequency of each utterance was analyzed with Praat phonetic analysis software.

Social rank. Emergent social rank was measured using three indices: group member-rated rank, outside observer-rated rank, and behavioral decision-making impact.

(1) Group member-rated social rank was derived from peers' posttask ratings of every other group member, on three items: "this person led the task," "this person had high status," and "this person was paid attention." Ratings were made on a 7-point scale (1 = *Not at all*; 7 = *Very much*). We used the Social Relations Model (Kenny, 1994) to calculate the *target effect* for each item, to capture each target's average rating after statistically removing idiosyncratic perceiver and dyadic relationship biases. The target effect scores of these items were averaged to form an overall measure of group-member rated rank (interitem $\alpha = .89$).

(2) Outside observer-rated rank was derived from judgments made by female undergraduate research assistants who were blind to our hypotheses. They watched the video-recordings of the group interactions in isolation and independently responded to the question "how influential was this individual over other group members," on a 5-point scale (1 = *Not at all*; 5 = *Extremely*; interrater $\alpha = .87$). Due to the large number of group recordings, two observers coded one half, and two other observers coded the other half. Ratings provided by the two observers for each participant were averaged to create an index of outside observer-rated rank.

(3) Behavioral decision-making impact was quantified as the degree to which each participant steered the group's collective decision closer to their own (Cartwright, 1959), by computing an index of similarity between each participant's initial private response on the task and the group's final collective response (see online supplementary material for details; Bottger, 1984).

Dominance and prestige. After completing the group-based decision-making task, participants rated each of the other group members on previously validated scales designed to assess perceptions of dominance and prestige (Cheng et al., 2010). These scales assess individuals' fear (e.g., "I'm afraid of her") and respect (e.g., "I respect and admire her") toward the target individual, and directly tap the interpersonal perceptions that indicate the effective establishment of a formidable or admirable appearance. Ratings were made on a 7-point Likert scale. We again used the Social Relations Model (Kenny, 1994) to compute target effect scores for each item, and then aggregated across the eight dominance items (interitem $\alpha = .93$) and the eight prestige items (interitem $\alpha = .89$) to form an overall measure of dominance ($M = 2.33$; $SD = .81$) and prestige ($M = 4.93$; $SD = .62$). Online supplemental Table S2 provides descriptive information on our key variables.

Results and Discussion

Pitch modulation and emergent social rank. To obtain a composite measure of emergent social rank for each participant, we computed standardized values (with mean of 0 and standard deviation of 1) for each of the three indices of social rank, then averaged across them ($\alpha = .68$). We focus on this rank composite in our primary analyses to minimize stochastic variation introduced by methodological differences between the three measures, and to derive a more precise indicator of individuals' social standing that incorporates different aspects of rank. However, the same qualitative results were obtained when we examined each of the three rank indices separately (see online supplementary material).

We analyzed these data using hierarchical linear modeling (HLM) to estimate an individual growth model (Bryk & Raudenbush, 1987). In contrast to OLS models, which capture only fixed effects and assume a single estimate for intercepts and slopes across the entire sample, this analytic approach incorporates random effects and allows for person-specific initial pitch and pitch trajectories. It allows us to examine how vocal pitch, measured across multiple instances at the within-person level, changes over time in the form of a pitch trajectory, and, more importantly, how this trajectory varies as a function of social rank (i.e., the moderator), measured at the between-person level. Although our primary interest was in the effect of initial pitch alterations on subsequent rank, which was addressed by examining the association between pitch alterations in the first few minutes of the interaction and emergent social rank assessed after the end of interaction, rank was treated as a moderator of the relation between time (the predictor) and vocal pitch (the outcome), to model individual growth in the form of pitch trajectories (Bryk & Raudenbush, 1987).

Specifically, we estimated the fundamental frequency of each person's three utterances (treated as the dependent variable in this analysis) as a function of the order of the utterance (hereafter, time; coded from 0, for the first utterance, to 2, for the third utterance), his or her social rank composite score (grand-mean centered), and the cross-level interaction between time and social rank, controlling for gender (with female = 1) and its interaction with time. This resulted in a growth model with random intercepts and random slopes to represent each individual's person-specific initial pitch and pitch trajectory, respectively, independent of the effects of gender. We tested the main hypothesis by examining the coefficient on the time × social rank interaction term, which indicates whether and how the pitch trajectories (represented by random slopes in the model) varied as a function of emergent social rank, independent of controls. A nonzero negative interaction would be consistent with the prediction that individuals who lower their pitch across the initial moments of the interaction eventually acquire high rank, whereas those who raise their pitch during those moments emerge as lower ranking. These analyses include data from 173 participants for whom pitch estimates were available (see online supplementary material for details on missing data).

Results indicated a significant negative time × social rank interaction predicting vocal pitch ($b = -4.45$, $SE = 1.33$, $p = .001$, .95CI[-7.05, -1.85]; see Table 1). Although the pitch trajectory of the average participant with moderate social rank showed a nonsignificant slight positive incline, individuals who emerged as low in rank showed a heightening pitch profile over time, whereas those who emerged as high rank showed a deepening pitch profile. This implies that the pitch trajectory of low ranking men and women (i.e., those whose social rank scores were 1 point below the grand mean) increased respectively by 5.31 Hz and 7.79 Hz over each subsequent utterance, or by 10.62 Hz and 15.58 Hz over the three utterances assessed. In contrast, the pitch trajectory of high ranking men and women (those whose social rank scores were 1 point above the grand mean) dropped respectively by 3.59 Hz and 1.11 Hz over each subsequent utterance, or by 7.18 Hz and 2.22Hz over the three utterances assessed. These average magnitudes of pitch increases and decreases exceed the just-noticeable difference threshold for human voices, which psychoacoustic studies have generally revealed to be roughly 2–4 Hz in this frequency range (Ladefoged, 1996; Sinnott, Owren, & Petersen, 1987; Smith, Patterson, Turner, Kawahara, & Irino, 2005). This analysis also indicates that, on average, individuals who eventually acquired higher rank began the interaction with a higher pitch than those who eventually occupied a lower rank; a 1-point increase in social rank was associated with a 6-Hz higher initial pitch (in the first utterance). However, mean pitch parameters (e.g., aggregated pitch across utterances) had little to no predictive power on social rank (see online supplementary material). Mean pitch trajectories also did not differ significantly by gender.

To illustrate this effect, Figure 1 plots the pitch trajectories for individuals who attained high rank (at the 90th percentile) and those who attained low rank (at the 10th percentile) for men and women separately, to capture differences in pitch elevation between the genders. On average, as rank increased from the 10th percentile to the 90th percentile, pitch trajectory changed by approximately −9 Hz per utterance or −18 Hz over three utterances.

Table 1
Hierarchical Linear Model Predicting Vocal Pitch From the Main and Interactive Effects of Time and Rank, Controlling for Gender and its Interaction With Time

Predictor variables	Regression coefficient (*SE*)
Time	.86 (1.26)
Social rank	5.85^{*} (2.43)
Time × Social rank	-4.45^{***} (1.33)
Gender (female = 1)	86.78^{***} (3.61)
Time × Gender	2.48 (1.89)
(Intercept)	114.08^{***} (2.41)
Observations	488
Clusters	173

Note. Coefficients are followed by standard errors in parentheses. Results indicate that social standing significantly predicts vocal pitch trajectories, in the form of a time × social rank interaction; a 1-point increase in social rank is associated with a 4.45 Hz drop in pitch per utterance.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

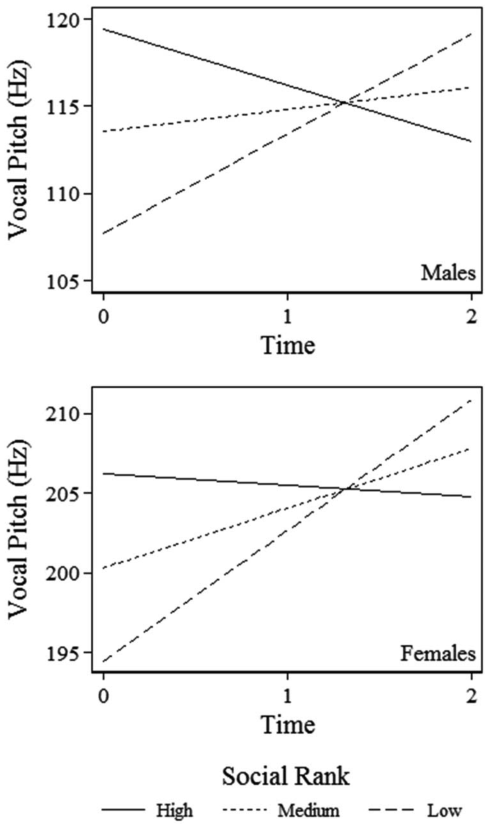

Figure 1. Fitted model of vocal pitch trajectory as a function of social rank. The dashed, dotted, and, solid lines show the pitch profile of individuals with a social rank score at the 10th, 50th, and 90th percentile, respectively. In contrast to low-ranking individuals, whose pitch trajectory rises over time, the vocal trajectory of high-ranking individuals deepens over time.

These results were robust to a variety of checks, which are presented in detail in the online supplementary material. First, alternative model specifications indicate that the effect is robust to the inclusion of additional controls, including age, height, weight, group size, and postural expansiveness (coded from video-recordings; online supplementary Table S3). Of these models, the one controlling for gender showed the best fit adjusted for model size (BIC), and is displayed in Table 1 and Figure 1; none of the other controls were significant. Second, reconfirming the predictive importance of the interaction between time and social rank reported above, goodness of fit measures (both AIC and BIC) indicate that across all models examined—with or without controls—the inclusion of the interaction term yielded a better fit (online supplementary Tables S3 and S4). Third, as noted, the same qualitative results were obtained in alternative models using each of the three separate rank indices, and when controls were included (online supplementary Table S6). Fourth, additional analyses using the simple difference between the pitch of the third utterance and first utterance (omitting the second)—a potentially more intuitive approach to assessing change (Rogosa & Willett, 1983)—converge with results from the growth model (online supplementary Table S8).

Pitch modulation and perceived dominance. We predicted that the impact of pitch alterations on rank outcomes occurs by virtue of diminishing or amplifying the vocalizer's perceived size, threat, competitive motivation, and formidability. We therefore predicted that pitch changes would be associated with the signaler's perceived dominance, but not prestige.

To test this account, we ran a separate growth model in which pitch was estimated as a function of time of utterance, peer ratings of dominance (grand-mean centered), peer ratings of prestige (grand-mean centered), and the cross-level interaction between time and both perceptions, controlling for gender and its interaction with time. Online supplementary Table S9 presents detailed results from this baseline model and other models with additional or fewer controls. As predicted, the time × dominance interaction term significantly and negatively predicted vocal pitch, independent of controls ($b = -2.84$, $SE = 1.17$, $p = .016$, .95CI[-5.14, $-.54$]), whereas the time × prestige term lacked significant predictive power ($b = -1.07$, $SE = 1.65$, $p = .518$, .95CI[-4.29, 2.16]. These results indicate that for each 1-point increase in perceptions of dominance, individuals showed a 2.84-Hz decline in pitch per utterance (for additional robustness checks see the online supplementary material, Tables S9 and S10). Taken together, these analyses indicate that the effects of pitch modulation on emergent social rank occur primarily through galvanizing and sustaining perceptions of dominance—rooted in fear and intimidation—and not via altering perceptions of prestige.

Study 2: The Causal Impact of Pitch Modulation on Perceptions of Rank-Seeking Intentions

Like all naturalistic observational studies relying on a correlational approach, the conclusions drawn from Study 1 are limited by the possibility of third-factor variables influencing observed effects. In addition, although these results are suggestive of a causal effect of change in pitch on emergent rank outcomes, given that pitch changes were assessed in the initial moments of the interaction and rank was assessed at its conclusion it remains possible that rank asymmetries emerged and stabilized very early on, such that our results instead capture the ways in which individuals modulate their pitch in response to appraisals of their current standing (Puts et al., 2006). To more directly test whether pitch alterations causally influence dominance perceptions and emergent social rank, in Study 2 we systematically manipulated the pitch trajectory of a vocal stimulus, and tested the causal impact of diverging pitch profiles on listeners' perceptions of vocalizers' rank-seeking motivations and dominance.

Method

Participants and procedure. Two-hundred, 74 participants (60.58% women) participated in an online experiment. These individuals were recruited from two sources: an undergraduate subject pool at a large Canadian university ($n = 181$) who completed the experiment for course credit, and the online labor market pool Amazon Mechanical Turk ($n = 93$), who received monetary payment. Of note, prior studies deploying a similar perceptual task (i.e., using voice recordings) have found similar effects across online and offline (in the laboratory) presentation formats (Feinberg, DeBruine, Jones, & Perrett, 2008). Participants' age ranged from 15 to 61 ($M = 23.62$, $SD = 7.64$), and none reported any hearing impairments or difficulty. To ensure that all participants could perform the listening task, they were required to first listen to a test audio track and correctly answer a series of questions about this recording. Participants who failed to correctly answer any test question were excluded from participation.

Following a standard forced-choice playback paradigm used extensively in prior research on voice judgments (R. C. Anderson & Klofstad, 2012; Apicella & Feinberg, 2009; Tigue et al., 2012), participants listened to two vocal stimuli that differed in pitch trajectory (deepening or rising) but were otherwise identical. After listening to both recordings for as many times as they wanted, participants chose which of the pair of voices they considered more descriptive of a series of eight traits. Specifically, to assess perceptions of rank-seeking intentions, participants were asked to indicate which voice appeared more assertive, and which sought more power, leadership, and control. To assess perceptions of dominance, participants indicated which voice appeared more intimidating and threatening. Finally, to assess perceptions of prestige, participants indicated which voice appeared more admirable and respectable. Order of the recordings and questions presented were counterbalanced across participants (see online supplementary material).

Experimental stimuli. To create a "master" voice recording from which two stimuli with diverging pitch trajectories were subsequently generated, a male research assistant read into a microphone three scripted statements from a fictional work conversation (see online supplementary material for details).

The master recording was finalized by standardizing the pitch of all three statements independently to 105 Hz. We then created two versions by manipulating the pitch of the first and last segment, without modifying the middle segment. In one version, the voice was altered to progressively deepen over the three statements. Specifically, the first segment was raised, and the last segment lowered, by 0.5 equivalent rectangular bandwidth (ERB), which is roughly equivalent to a perceived shift of ± 20 Hz; a change that is readily discernible and widely used in studies of pitch perceptions (Feinberg, Jones, Little, et al., 2005; Klofstad et al., 2012; Puts, Barndt, Welling, Dawood, & Burriss, 2011). In the other version, the voice was altered to progressively rise over the three statements. Specifically, the first segment was lowered and the last segment raised by 0.5 ERB. The three statements within each version were compiled into a single continuous recording.

The resultant pair of stimuli thus contained identical verbal content and virtually the same mean pitch across the entire recording, but differed in whether the pitch progressively deepened or rose across the three segments. All pitch manipulations were made independent of other acoustical properties (see online supplementary material).

Analytical approach. For all trait perceptions assessed, responses were coded 0 for choice of the deepening pitch recording, and 1 for the rising pitch recording. To derive an overall measure of perceived desire for social rank, we averaged the coded responses across the four relevant traits, which were highly intercorrelated (tetrachoric *r*s ranged from .69 to .78) and scaled together reliably (interitem $\alpha = .81$; $M = .41$, $SD = .39$). Responses on the two dominance items (tetrachoric $r = .96$) were similarly aggregated (interitem $\alpha = .90$; $M = .44$, $SD = .47$), as were the responses on the two prestige items (tetrachoric $r = .70$; interitem $\alpha = .66$; $M = .53$; $SD = .43$).

These three aggregate variables provide a summary measure of listeners' tendency to perceive greater rank-seeking, dominance, and prestige in the recording with a deepening pitch profile, compared to the recording with a rising pitch profile. Lower values indicate a tendency to choose the deepening pitch recording as more descriptive of these traits, and higher values indicate a tendency to choose the rising pitch recording. Single sample Wilcoxon signed-ranks test were used to test the mean perception indices across the entire sample against 0.50, which would be the summary index expected if individuals randomly chose between the deepening and rising voices.

Results and Discussion

As predicted, a Wilcoxon signed-ranks test indicated that listeners judged the deepening voice as expressing a greater desire for social rank than the rising voice ($z = -3.55$, $p = .0004$). Separate analyses using each of the four discrete items that comprise this measure revealed the same pattern; the deepening voice was more likely to be seen as assertive ($z = -2.30$, $p = .022$), and as seeking power ($z = -3.26$, $p = .001$), leadership ($z = -2.90$, $p = .004$), and control ($z = -3.02$, $p = .003$), relative to the rising voice. The size of these effects is comparable to previously documented effects of stable (i.e., rather than shifting) vocal pitch on leadership perceptions, using forced-choice playback designs (Klofstad, 2015; Klofstad et al., 2012).

Turning to perceptions of dominance and prestige, we found that listeners judged the deepening voice as more dominant ($z = -2.22$, $p = .027$ than the rising voice). Also as predicted, perceptions of prestige were not influenced by pitch profiles ($z = .98$, $p = .327$; see online supplementary Figure S2). These analyses were robust to the inclusion of controls to account for possible differences in participant gender, age, method of recruitment (student vs. Mechanical Turk), and stimuli order; *p*s = .035 and .795 (see online supplementary material, Table S11), though the effect of manipulated pitch on perceived rank, despite maintaining a comparable effect size, became only marginally significant when these controls were applied ($p = .115$). See the online supplementary material for details and additional analyses.

General Discussion

The present results support the prediction that humans signal rank intentions partly through systematic changes in vocal pitch, and these changes shape perceptions of relative formidability and the outcome of rank contests. By combining an externally valid observational study with an internally valid experiment manipulating perceived pitch alterations, the present research both examined the impact of dynamic changes in pitch as they actually occur in real-world rank contexts, and provided evidence for the causal impact of these alterations on rank outcomes. More specifically, Study 1 revealed that individuals interacting in face-to-face groups show spontaneous variation in the magnitude and direction of their pitch alterations, and these alterations predict their likelihood of winning or losing rank contests, such that individuals who raise their pitch over the initial moments of an interaction emerge as low-ranking, whereas those who deepen their pitch come to occupy higher ranks. Study 2 extended these findings by confirming that vocal changes, even in the absence of other accompanying behavioral signals, can causally influence perceptions of formidability and domination.

The present findings converge with and expand upon prior research on the use of pitch modulations to strategically signal self-assessed formidability. Puts and colleagues (2006) found that men who consider themselves physically stronger lower their pitch when addressing a potential adversary, whereas those who consider themselves physically weaker raise their pitch. By broadening the scope of our investigation to the effects of this behavioral trait on the senders' emergent social rank and receivers' perceptions of these individuals, our results extend this prior work by demonstrating that strategic pitch changes—which are best interpreted as one of many evolved cues of dominance used by senders and receivers to readily establish relative formidability—systematically predict listeners' perceptions and actual rank outcomes.

Theoretical Implications

These findings are consistent with the notion that humans evolved to deploy dynamic vocal signals, along with a diverse and broader suite of cost-minimizing behavioral cues, that function to signal one's willingness to inflict costs on competitors, and consequently to enhance or dampen the signaler's apparent threat (Dovidio et al., 1988; Fournier et al., 2002; Marsh et al., 2014; Tiedens & Fragale, 2003). Moreover, these results are consistent with the expectation that our species is equipped with a specialized battery of perceptual biases designed to extract information from these vocal signals, to accurately estimate a rival's competitive motivation and relative formidability, and facilitate advantageous decisions about whether to defer or escalate in conflicts.

This evolutionary explanation for the observed effects contrasts with proximal explanations that focus on culturally acquired and reinforced gender associations and stereotypes. The cultural association hypothesis emphasizes that deference toward rivals who speak in lower voices and display other masculine cues derives strictly from cultural beliefs, institutions, and practices that confer status to men or individuals who exhibit masculine traits, without any functional basis. One implication of this view is that in other societies vocal pitch may not be associated with dominance at all, or deeper pitch voices might signal submission or shame. Two aspects of our findings, however, challenge this expectation. First, our results indicate that lowering pitch enhances dominance but not prestige—whereas the latter would be expected, as well, from a cultural association account, given cultural beliefs linking men to competence and success (Eagly & Mladinic, 1994).

Second, we found that both men and women spontaneously deploy pitch modulation signals to effectively exaggerate their formidability, suggesting that this is not only a signal for men. Furthermore, recent evidence suggests that the dominance avenue to social rank operates effectively in both genders, and influences group decision making, deference, and attention (Cheng et al., 2013, 2010; Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010). Although men and women may ultimately differ in their use of numerous specific tactics to effectively advertise and exaggerate their threat and formidability in efforts to prevail in dominance disputes—with males' preferences tailored toward direct and aggressive physical combat, in contrast to females' more indirect and low-cost aggressive tactics (e.g., shunning, gossiping, ostracizing; Archer, 2004; Campbell, 1999)—our findings suggest that within the vocal domain, pitch modulation signals operate similarly across both genders to augment (or diminish) dominance rank. These results are consistent with prior experimental work showing that lower pitched female (and male) voices are deemed more dominant by listeners of both genders (Jones et al., 2010), and that female listeners tend to be more sensitive to this dominance cue in female voices, and reveal a stronger perceptual bias than male listeners (Borkowska & Pawlowski, 2011). Similarly, in electing political leaders, men and women not only prefer female candidates with lower voices—even when the contested leadership role is feminine in nature (e.g., President of the Parent Teachers Organization; R. C. Anderson & Klofstad, 2012)—but this preference is stronger when evaluating female candidates than male candidates (Klofstad, 2015). In light of these prior results, it is not surprising that we found the same qualitative relationship between a deepening pitch profile and greater dominance and social rank in men and women.

Moreover, evidence from two other lines of research, which converge with the evolutionary-based explanation, also challenges the cultural association explanation. First, a strict cultural learning explanation cannot readily account for the well-documented pitch- and pitch modulation-regulated patterns of dominance and submission observed across a wide range of nonhuman animals (Bee et al., 1999; Davies & Halliday, 1978; Morton, 1977; Morton & Page, 1992; Owings & Morton, 1998; Ryan & Brenowitz, 1985; Vannoni & McElligott, 2008; Wagner, 1992), and in evolutionarily relevant small-scale societies (Apicella, Feinberg, & Marlowe, 2007; Hodges-Simeon et al., 2014; Puts et al., 2012). The Hadza hunter-gatherers in Tanzania are particularly relevant here, as they are known for their relatively gender egalitarian social norms and matrilocal biases. Despite these features of Hadza society, a deeper vocal pitch is associated with higher status among these individuals (Apicella & Feinberg, 2009; Apicella et al., 2007). This commonality across species and human societies is consistent with the notion that submission to individuals with deeper pitched voices arises primarily from an evolved psychology.

Second, it is not clear how the cultural association explanation might account for emerging evidence of a biological underpinning of vocal pitch, and its effects on mate choice. For example, studies suggest that higher levels of testosterone are linked to low pitch in men (Bruckert et al., 2006; Dabbs & Mallinger, 1999; Harries et al., 1998; Puts et al., 2012), and women show a stronger preference for lower pitched men during the fertile period of their ovulatory cycle (Feinberg et al., 2006; Puts, 2005), nonlactating phases (Apicella & Feinberg, 2009), and in short-term mating contexts (Puts, 2005). These findings are consistent with—and predicted a priori by—the evolutionary approach, which proposes that low vocal pitch and other masculine displays (e.g., facial masculinity, body symmetry) function as androgen dependent traits that signal threat potential, resource acquisition capacity, and mate quality (Andersson, 1994; Apicella et al., 2007; Feinberg, 2008; Gangestad, Simpson, Cousins, Garver-Apgar, & Christensen, 2004; Penton-Voak & Perrett, 2000; Puts et al., 2012). In contrast, it is not clear why and how cultural institutions and systems alone would give rise to women's capacity to discern among these features and to use them strategically to guide their mate choice under different ovulatory and lactation statuses. Nonetheless, firm conclusions about whether these dominance signals represent evolved aspects of human psychology, and the role of cultural traditions and expectations in shaping or increasing the influence of pitch on social perceptions, await future work, ideally including studies that examine the generalizability and variability of these signals across a diverse range of environments and populations.

The present results also bear implications for signaling theory, an extensive theoretical program aimed at understanding how selection has shaped behavioral, physiological, and morphological characteristics designed to facilitate communication and informational exchange between organisms (Bird & Smith, 2005; Smith & Harper, 1995; Otte, 1974; Rendall, Owren, & Ryan, 2009). Central to this enterprise is the concept of signal honesty, which considers the degree to which a signal accurately (though not necessarily perfectly) encodes information about the signaler's underlying qualities, such as size, condition, or intention (Smith & Harper, 2003; Searcy & Nowicki, 2005; Zahavi, 1975; Zahavi & Zahavi, 1997). Does vocal pitch provide an honest signal of an individual's formidability? The evidence, across different formidability-relevant characteristics and traits, appears mixed. With regard to body size and strength—the primary physical determinants of fighting potential across species, including humans (Archer, 1988)—the answer may be no; studies have generally shown weak to null associations between pitch and physical size and upper-body strength within sexes (Collins & Missing, 2003; Rendall, Vokey, & Nemeth, 2007; Sell et al., 2010; but see Evans et al., 2006; Puts et al., 2012). On the other hand, there is considerable evidence linking vocal pitch to testosterone, which is associated with physical aggressiveness and hostility (Archer, 1991, 2006; Aromäki, Lindman, & Eriksson, 1999; Book, Starzyk, & Quinsey, 2001), consistent with the notion that deep voices serve as an honest advertisement of threat potential (Bruckert et al., 2006; Dabbs & Mallinger, 1999; Evans et al., 2008; Puts et al., 2012).

With regard to threat intentions, the present results, combined with other evidence linking deepening voices and self-appraised or imminent dominance (e.g., attacking) in humans (Gregory et al., 2001; Gregory & Webster, 1996; Puts et al., 2006), tentatively suggests that a lowering pitch may honestly signal a motivation and readiness to vie for dominance in rank competitions. Beyond advertising competitive intentions, however, the extent to which this signal correlates with the producer's strength or other formidability enhancing qualities to also function as an honest signal of fighting potential, is an interesting question for future inquiry. Future work should also further explore the effects of pitch changes on perceivers' behaviors, such as patterns of deference, attention, and escalation.

Limitations and Future Directions

These findings open up several avenues for potentially fruitful future work. One area concerns the vocal dynamics that underpin rank contests in women. For example, given that we examined the causal effects of pitch change in a male voice only, subsequent work should directly address whether listeners also readily extract dominance information from female speakers' pitch modulations. The results of Study 1, which indicate a highly consistent pattern of effects across female and male groups, ameliorate this concern to some extent, but future research is needed to examine the effects of pitch alterations in mixed-gender contests. In fact, one prior study hints at the possibility that lowering versus rising pitch signals may have differential effects on rank attainment in competitions against rivals of the opposite sex (Klofstad, 2015), but more work is needed in this area.

Another area ripe for future research involves the role of situational changes in vocal pitch in the related domain of mating preferences. A growing number of studies suggest that women have a generalized preference for deeper male voices (Collins, 2000; Feinberg et al., 2006; Feinberg, Jones, Little, et al., 2005; Hodges-Simeon, Gaulin, & Puts, 2010), and a study examining the aforementioned matrilocally inclined hunter-gatherers found that men in this society with lower-pitched voices have greater reproductive success (Apicella et al., 2007). In contrast, men have a generalized preference for higher-pitched female voices (Feinberg, Jones, DeBruine et al., 2005; Feinberg et al., 2008), which (like other expressions of femininity) signal reproductive health and fertility, hormonal profile, and age (Bryant & Haselton, 2009; Collins & Missing, 2003; Thornhill & Gangestad, 1999). While these existing studies link stable between-person variation in vocal pitch to differential mate value and attractiveness, more research is needed to examine how within-person vocal changes operate in mating contexts, and potentially covary with hormonal variation and ovulation cycles (Amir & Biron-Shental, 2004; Bryant & Haselton, 2009).

An additional important direction for future work entails examining whether and how pitch changes operate in zero-sum competitions, and whether effects differ from those observed in the collaborative team environment examined here. One possibility is that, in zero-sum, competitive contests, a deepening voice may be used to cue one's competitive intentions and likelihood of success. Research on hormone changes suggests that winners of skill-based contests devoid of agonistic conflicts (e.g., chess matches, cognitive competitions involving puzzles) experience postvictory momentary surges in testosterone (Mazur, Booth, & Dabbs, 1992; Mehta & Josephs, 2006; Zilioli & Watson, 2012), which may in turn produce a corresponding drop in vocal pitch (Harries et al., 1998). These findings raise the possibility that, in contrast to collaborative team environments in which knowledgeable and capable individuals should suppress deepening vocal signals so as to avoid appearing dominant and risk losing prestige in the eyes of one's group members, in zero-sum exchanges the relatively more successful (prestigious) competitor may emit pitch changes that cue his or her entry into a competitive state.

Finally, several methodological limitations of the present research should be addressed in future work. First is the absence of external incentives (e.g., experimental rewards or punishments) provided for rank attainment (to be clear, participants in our study were given a team incentive for correct responses on the task, but there was no incentive for group members to compete against each other for any kind of rank or status). Even in the ecologically valid situation of completing a group task in Study 1, participants might not have been strongly motivated to pursue high rank; the rewards of attaining high rank within contrived laboratory groups may not be entirely clear, and could be considered largely psychological. However, these psychological benefits should not be underestimated. Converging lines of behavioral, cross-species, and neuroscientific evidence suggest that attaining high rank is intrinsically rewarding, motivating, and universal (C. Anderson, Hildreth, & Howland, 2015; Martinez et al., 2010; Tamashiro, Nguyen, & Sakai, 2005). Nonetheless, one important future research direction is to examine vocal signal dynamics when individuals are directly incentivized to acquire high rank in a wide range of contexts and groups.

A second methodological limitation concerns our measure of pitch, which likely provides a rough and limited proxy for the full range and extent of the actual vocal changes produced, as pitch was derived from assessing only three vocal samples rather than over a longer time span. We expect that the actual pitch change signals we are ultimately seeking to understand in dominance contests are more salient and exaggerated than those documented here. Future work should examine vocalizations generated over the full duration of interactions to establish the precise magnitude and strength of pitch change signals displayed in rank contests and employ psychoacoustic studies to assess the perceptual relevance of these (possibly larger) naturally occurring pitch changes.

Despite these limitations and important future research directions, the present findings provide strong support for the suggestion that: (a) pitch alteration signals are produced spontaneously and strategically in real face-to-face rank contests; (b) receivers both detect pitch changes and use the reliable information provided by these signals to accurately gauge rank intentions; and (c) these vocal signals influence senders' perceived formidability, and predict who prevails and who submits in a contest. Combined with prior work, our findings are consistent with the idea that humans rely on systematic vocal changes, alongside a broad suite of other evolved behavioral signals, to track, signal, and coordinate hierarchical relationships.

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