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The Sound of Power: Conveying and Detecting Hierarchical Rank Through Voice

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Abstract

The current research examined the relationship between hierarchy and vocal acoustic cues. Using Brunswik's lens model as a framework, we explored how hierarchical rank influences the acoustic properties of a speaker's voice and how these hierarchy-based acoustic cues affect perceivers' inferences of a speaker's rank. By using objective measurements of speakers' acoustic cues and controlling for baseline cue levels, we were able to precisely capture the relationship between acoustic cues and hierarchical rank, as well as the covariation among the cues. In Experiment 1, analyses controlling for speakers' baseline cue levels found that the voices of individuals in the high-rank condition were higher in pitch and loudness variability but lower in pitch variability, compared with the voices of individuals in the low-rank condition. In Experiment 2, perceivers used higher pitch, greater loudness, and greater loudness variability to make accurate inferences of speakers' hierarchical rank. These experiments demonstrate that acoustic cues are systematically used to reflect and detect hierarchy.

Keywords

social cognition, social perception, open data, open materials

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The sound of hierarchy is distinctive. From the thunderous proselytizing of generals directing soldiers into battle to the warning cries of high-status baboons telling competitors to back away, those in authority seem to speak in a different voice. In the research reported here, we investigated how hierarchical rank affects the objective acoustic properties of speakers' vocal cues. Furthermore, we examined the extent to which perceivers, in turn, use these acoustic cues to accurately infer speakers' hierarchical rank. Collectively, the studies provide a detailed account of the relationship between hierarchy and acoustics that simultaneously takes into consideration both the speakers' and the perceivers' perspectives.

Social Hierarchy

Hierarchy is the predominant form of social organization, and it permeates societies and organizations (Fiske, 1992; Magee & Galinsky, 2008; Sidanius & Pratto, 1999). A number of theories propose that its prevalence stems from the fact that hierarchy solves the inherent problem of organizing a collection of individuals (van Vugt, Hogan, & Kaiser, 2008). We define hierarchy as a situationally determined rank order of individuals, with some individuals having more power, status, or authority than others (Magee & Galinsky, 2008). Instantiations of hierarchy include both formal hierarchies (e.g., an organizational ladder) and informal ones (e.g., status differences in a college dorm).

We make an important distinction between hierarchy and dominance (like Hall, Coats, & Smith LeBeau, 2005, we use "verticality" to refer to both of these constructs). Hierarchy is based on external factors (e.g., resources, status), and thus is dynamic, such that members of a group ascend or descend in rank across time (e.g., from middle to upper management). Rank is context and situation dependent. For example, an untenured faculty

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member is higher ranked when interacting with a doctoral student but lower ranked when interacting with a tenured, senior faculty member.

In contrast, dominance is based on the physical characteristics of individuals, such as body size and testosterone level, and tends to be invariant within individuals (Hodges-Simeon, Gaulin, & Puts, 2010; Puts, Gaulin, & Verdolini, 2006; Puts, Hodges, Cárdenas, & Gaulin, 2007). Consider differences between men and women: Sex differences in body size and testosterone, called sexual dimorphism, make men more dominant than women. These sexually dimorphic characteristics also vary *within* each sex, with some women being larger than others, and some women even appearing more dominant than some men.

Theoretically, there is consensus about the importance of distinguishing between dominance and hierarchy (Burgoon & Dunbar, 2000; Hall et al., 2005). In practice, unfortunately, research examining verticality often conflates the two, so it is difficult to determine whether it was hierarchy or dominance that was really studied in a given work. This may explain why the small body of work on the acoustic properties of verticality has produced mixed results for the most commonly examined cue: pitch. Before discussing why the acoustics of hierarchy may differ from that of dominance, we detail why vocal cues may offer an ideal window into hierarchy.

Vocal Cues: A Window Into Hierarchy

For hierarchy to function as an organizing principle, it is critical that targets express and perceivers discern cues to contextual rank quickly and accurately. Given the pervasive impact of nonverbal cues on person perception, the incredible malleability of some of these cues, and their ubiquity in social situations (Ambady & Rosenthal, 1992), nonverbal cues may be critical to how hierarchy is reflected and detected. We chose to study vocal cues because multiple sources suggest that they serve as exceptionally informative cues to hierarchy (Dunbar & Burgoon, 2005; Zuckerman, Amidon, Bishop, & Pomerantz, 1982). In a meta-analysis on the relationship between nonverbal cues and verticality, Hall et al. (2005) found that a greater number of vocal than visual cues were associated with verticality. Furthermore, Bugental and Love (1975; Bugental, Henker, & Whalen, 1976) found that parents' vocal tone had a stronger impact on their children's problematic behavior than did parents' verbal content, which suggests that vocal cues carry greater weight and authority than linguistic ones.

Acoustics, dominance, and hierarchy

A small body of research has explored how the objective acoustic properties of voice relate to what the researchers have referred to as dominance. The most commonly examined cue has been pitch (i.e., fundamental frequency, which is an index of the frequency of the vocal folds' vibration in producing phonation; Fitch, 1994; Tusing & Dillard, 2000). Some work has found a negative relationship between pitch and dominance (Apple, Streeter, & Krauss, 1979; Ohala, 1982). Other work has yielded a positive association (Scherer, London, & Wolf, 1973; Scherer & Oshinsky, 1977; male voices in Tusing & Dillard, 2000). Yet other work has shown null effects (Aronovitch, 1976; Bruckert, Lienard, Lacroix, Kreutzer, & Leboucher, 2006; Hodges-Simeon et al., 2010; Puts et al., 2006; female voices in Tusing & Dillard, 2000).

These contradictory findings for pitch may seem surprising, but closer inspection reveals that loose use of the term *dominance* has contributed to this empirical confusion. Indeed, this lack of clarity is apparent even in the definitions given to the perceivers who have been asked to judge target voices: Some definitions have emphasized using power and control to make these judgments (e.g., Tusing & Dillard, 2000), whereas others have emphasized using physical superiority (e.g., Hodges-Simeon et al., 2010). The former type of definition is more closely connected to hierarchy, and the latter to dominance. When we divided previous studies according to which type of verticality they focused on, we noticed that all of the work concerned with dominance—whether it involved perceptions or encoding—consistently yielded either negative or null relationships with pitch (Aronovitch, 1976; Ohala, 1982; Puts et al., 2006), whereas positive relationships with pitch emerged in the studies concerned with hierarchy, or power (Scherer et al., 1973; Tusing & Dillard, 2000).

One other acoustic cue for which it is possible to differentiate whether the existing empirical data refer to hierarchy or dominance is resonance (i.e., formant dispersion; Puts et al., 2007). Puts et al. used the terms "physical dominance" and "social dominance" to refer to the two types of verticality in their report. It is well established that resonance is a fundamental cue to perceptions of sexual dimorphism (Fitch & Giedd, 1999; Puts, Apicella, & Cárdenas, 2012), and Puts et al. found that a speaker's resonance had a much weaker relationship with perceptions of social than physical dominance. This finding supports our assertion that the acoustic patterns associated with hierarchy may be different from those associated with dominance.

Methodological considerations

The current research examined whether acoustic cues are used to achieve accuracy in hierarchy-based inferences (i.e., inferences about whether a person holds a high- or low-rank position). The closest previous approximation to our study, albeit without precise acoustic measures, is the meta-analysis by Hall et al. (2005). However, although Hall et al. looked at both actual studies (i.e., how verticality affected a target's nonverbal

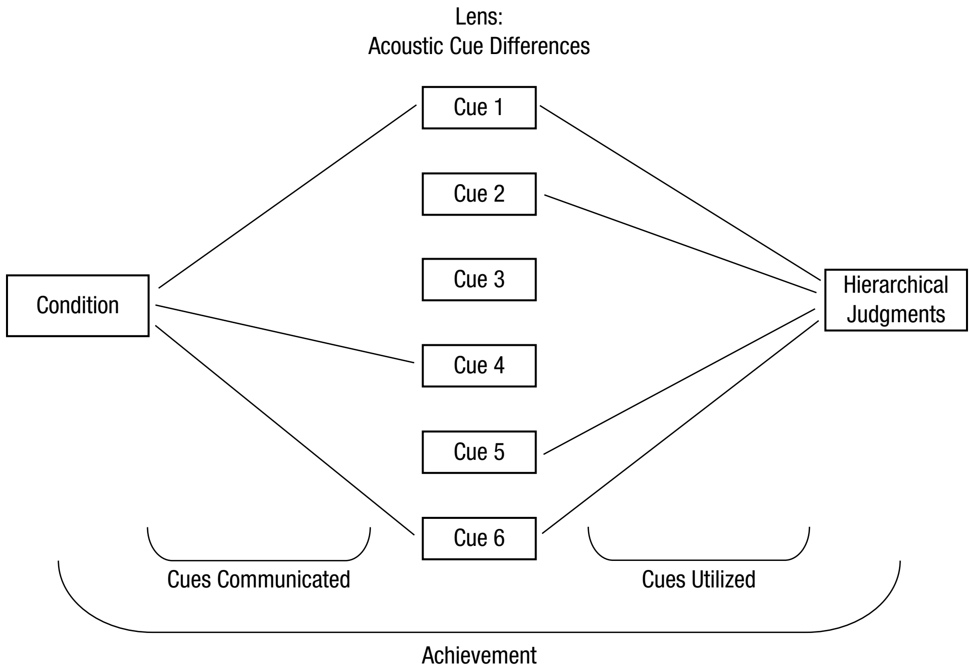

Fig. 1. Application of Brunswik's (1956) lens model to investigate the link between hierarchy and acoustic cues. Experiment 1 examined the relationships between six acoustic cues and speakers' manipulated hierarchical rank. Experiment 2 examined perceivers' use of these six cues in making judgments about the speakers' hierarchical rank as well as the accuracy of these judgments (i.e., achievement).

cues) and studies of beliefs (i.e., perceptions of verticality based on different cues), their meta-analysis could not assess perceivers' accuracy in inferring hierarchical rank because the beliefs studies tested whether a cue was perceived to be associated with a particular hierarchical rank regardless of whether the cue was actually associated with that hierarchical rank. To assess accuracy adequately, one needs to examine targets' conveyance of their hierarchical rank via nonverbal cues, assess perceivers' hierarchy-based inferences of the targets, and determine the extent to which perceivers use the nonverbal cues to achieve accuracy, all in a single research setting. Further, similar operationalizations of hierarchy must be provided to targets and perceivers. The most direct way to test whether people use acoustic cues to accurately identify a person's hierarchical rank would be to examine the effect of each cue while taking into account the effect of all of the cues concurrently, to control for any covariation among the cues (Zebrowitz & Collins, 1997). Our research included all of these necessary features to adequately assess the accuracy of perceivers' hierarchy-based inferences and the role of acoustic cues in achieving accuracy.

Finally, acoustic cues based on hierarchical rank are likely to be subtler than those based on sexual dimorphism. Therefore, in studies involving a manipulation of speakers' hierarchical rank, it is necessary to control for speakers' acoustic cues prior to the manipulation (i.e., baseline acoustics). If there is no control for baseline acoustics, the effect of situationally based hierarchical rank will be confounded with dominance.

Brunswik's Lens Model

We propose that vocal cues systematically reflect rank and can be accurately perceived. We used Brunswik's (1956) lens model to understand the relationship between hierarchy and acoustics. This model provides a framework for systematically investigating the link between hierarchy and acoustics from both the speakers' and the perceivers' perspectives (Fig. 1; see the Supplemental Material available online for additional details on the lens model). In Experiment 1, we manipulated the hierarchical roles of speakers and assessed the impact of this hierarchy manipulation on their acoustics. Thus, we examined the objective ways in which speakers' acoustics differ as a function of hierarchical role (i.e., *cues communicated*, to the left of the lens in Fig. 1). In Experiment 2, we had perceivers listen to the vocal clips from Experiment 1 and make inferences about the speakers' hierarchy-related behaviors. Thus, we examined how acoustic differences are used by perceivers to make hierarchy-related inferences about speakers (i.e., *cues utilized*, to the right of the lens in Fig. 1).

The final component of the lens model is *achievement* (Brunswik, 1956): the extent to which the left and right sides of the lens correspond. In the current research, this would be the accuracy of acoustics-based inferences of hierarchy. We examined achievement in two ways. First, we assessed whether perceivers were able to judge speakers' objective rank accurately. Second, we conducted path analyses using data from Experiments 1 and 2 to investigate the role of acoustic cues in mediating the relationship between speakers' actual rank and perceivers' inferences of the speakers' rank-related behaviors.

Six Acoustic Cues

We measured acoustic cues, the voiced elements of vocal cues that have quantifiable physical properties (e.g., loudness is measured in decibels). In contrast, pauses, silences, and speech rate—nonvoiced elements of vocal cues—have no measurable physical properties beyond their number, duration, and speed, respectively.

Our choice of acoustic cues was guided by established acoustic research procedures and findings (Coleman, 1976; Fitch, 1997; Ko, Judd, & Blair, 2006). In addition, we wanted to study cues that seem to represent unique facets of the voice. We decided to focus on mean pitch and pitch variability, mean loudness and loudness variability, and mean resonance and resonance variability. Pittman (1987) proposed pitch and loudness as two distinct facets of the voice. Fitch (1997; Fitch & Giedd, 1999) demonstrated that resonance is another distinct facet and introduced its measurement through formant dispersions, which are positively correlated with body size (i.e., the larger the body, the more resonant, or sonorous, the voice). Many mammals use this cue to gauge the size of a vocalizer (Fitch, 1994).

Despite claims that these cues represent unique facets of the voice, no research has examined all of these cues together, especially via precise acoustic measurements. In the current work, we obtained precise acoustic measurements of these cues and examined their covariation to assess empirically the extent to which these cues are, in fact, distinct facets of the voice.

Experiment 1: Hierarchy Reflected in Speakers' Acoustic Cues

Experiment 1 explored how hierarchy affects speakers' six acoustic cues. We recorded speakers' baseline voices, manipulated their hierarchical role, and then recorded their voices in their assigned roles to capture the objective properties of their baseline and hierarchy-induced acoustics.

Method

Speakers. The speakers in this experiment were 161 undergraduates (80 male). The sample size was determined in advance.

Baseline acoustics. To capture baseline acoustics, we first recorded the speakers reading the Rainbow Passage (Fairbanks, 1940, p. 127; Ko et al., 2006). They were then told that they would be involved in a negotiation exercise.

Hierarchical-rank manipulation. We randomly assigned the speakers to either the high-rank or the low-rank condition. We also assigned speakers to four different types of hierarchy. Speakers in the *high-rank condition* were told to imagine that they had (a) a strong alternative offer, (b) valuable inside information, or (c) high status in the workplace, or (d) were asked to recall an experience in which they had power (Galinsky, Gruenfeld, & Magee, 2003; for manipulation details, see Table 1). Speakers in the *low-rank condition* were told to imagine that they had (a) a weak alternative offer, (b) no inside information, or (c) low status in the workplace, or (d) were asked to recall an experience in which they lacked power. Having strong alternatives and inside information are the two foundations of power in negotiations (Fisher, Ury, & Patton, 1991), status is a key basis of hierarchical differentiation (Magee & Galinsky, 2008), and thinking about experiences with power produces the same effects as having actual power (Galinsky et al., 2003). Because the type of hierarchical manipulation did not moderate the effects observed (see the Supplemental Material for details), we collapsed the data across this factor.

We next recorded the speakers saying aloud the Negotiation Passage: "I'm glad that we are able to meet today and I am looking forward to our negotiation. I know that you and I have different perspectives on some of the key issues and that these differences would need to be resolved for us to come to an agreement." Finally, speakers responded to a manipulation check: "How powerful did you feel in your role?" The response scale ranged from 1 (*not at all powerful*) to 7 (*very powerful*). (Additional details about the speakers and procedure are provided in the Supplemental Material.)

Acoustic measurements

Pitch. Our index of pitch was fundamental frequency, measured in hertz. Higher-pitched voices have higher fundamental frequencies. We also measured pitch variability (variance of the fundamental frequency). Greater variability in pitch corresponds to a less monotone voice.

Table 1. Role Information Provided to Speakers in the High-Rank Condition of Experiment 1

Rank manipulation	Instructions
Inside information	One of the advantages you have going into this negotiation is that you have valuable inside information about the other party in the negotiation. Because of this information, you have a very good idea of what you can get out of this deal and how to leverage this information to get a deal to your liking. This means that you do not have to settle for just any kind of deal.
Strong alternatives	One of the advantages you have going into this particular negotiation is that you have a strong alternative offer. Hence, you will only agree to a deal if the terms are to your liking. Otherwise, you would be perfectly fine with walking away from the negotiation without a deal because you could pursue the attractive alternative offer instead.
High status	One of the advantages that you have going into this negotiation is that your position in your company gives you a tremendous amount of status. You know that the other side is aware of the fact that you are highly respected and have high social standing.
Sense of power	One of the advantages that you have going into this negotiation is that you feel a general sense of powerfulness. To help you get into this feeling of powerfulness, think of any past situation where you felt really powerful. Now apply that past feeling to your current negotiator role.

Note: Speakers in the low-rank condition were provided with the inverse of the details in this table.

Resonance. The resonance of the voice is akin to the timbre of an instrument and is orthogonal to pitch. For example, a violin and a cello playing the same middle C will have quite different resonant qualities (a cello is more resonant). Resonance was measured by formant dispersion (Fitch, 1997), which is derived by averaging the difference in frequency between adjacent formants (and is also measured in hertz). When formant frequencies are closer together, formant dispersion is lower, which translates to a more resonant, or sonorous, voice. We also measured resonance variability (variance of formant dispersion).

Loudness. Loudness was measured in decibels; higher values correspond to louder voices. We also measured loudness variability (variance in loudness).

Software. We used Praat software (Boersma & Weenink, 2008) to obtain data on fundamental frequency, loudness, and the frequencies of the first three formants for each speakers' two recording (i.e., the baseline Rainbow Passage and the postmanipulation Negotiation Passage). The six acoustic variables were computed for each speaker separately for each passage.

Table 2. Results From Experiment 1: Partial Intercorrelations (Speaker's Sex Partialed Out) Among the Six Acoustic Cues (n = 161)

Acoustic cue	2	3	4	5	6
1. Pitch (f_0)	.14	.18*	.10	.01	.10
2. Pitch variability	—	.01	.08	−.20*	.07
3. Loudness		—	.01	−.45**	.03
4. Loudness variability			—	−.01	−.01
5. Resonance (D_f)				—	.06
6. Resonance variability					—

Note: f_0 = fundamental frequency; D_f = formant dispersion (lower values denote a more resonant, or less shallow-sounding, voice). *p < .05. **p < .01.

Results

Manipulation check. Speakers in the high-rank condition felt more powerful (M = 5.21, SD = 0.89) than did speakers in the low-rank condition (M = 3.43, SD = 1.33), $F(1, 157) = 99.60$, $p < .001$.

Intercorrelations among baseline acoustics. To test whether the six acoustic cues represent unique facets of the voice, we examined their intercorrelations in the baseline recordings, partialing out speaker's sex (Table 2). The fact that there were so few significant correlations overall is preliminary evidence that these cues capture facets of the voice that are largely unique. (See Table 3 for descriptive statistics for the baseline recordings and effects of speaker's sex on baseline acoustic cues.)

The impact of hierarchical rank on speakers' acoustic cues. Each of the six hierarchy-based (i.e., postmanipulation) acoustic variables was submitted to a 2 (condition: high rank, low rank) × 2 (speaker's sex: female, male) between-subjects analysis of covariance, controlling for the corresponding baseline acoustic variable. Table 4 presents the adjusted means by condition.

Condition had a significant effect on pitch, pitch variability, and loudness variability. Speakers' voices in the high-rank condition had higher pitch, $F(1, 156) = 4.48$, $p < .05$; were more variable in loudness, $F(1, 156) = 4.66$, $p < .05$; and were more monotone (i.e., less variable in pitch), $F(1, 156) = 4.73$, $p < .05$, compared with speakers' voices in the low-rank condition (all other Fs < 1; see the Supplemental Material for additional analyses of

Table 3. Results From Experiment 1: Descriptive Statistics for the Six Baseline Acoustic Cues and Effects of Speaker's Sex on These Cues

Acoustic cue	Female speakers	Male speakers	Effect of speaker's sex: $t(159)$
Pitch (f_0, in Hz)	186.16 (19.11)	112.52 (15.27)	26.99**
Pitch variability (Hz)	1971.82 (794.61)	1530.34 (1536.38)	2.29*
Loudness (dB)	56.42 (3.63)	58.51 (3.97)	−3.48**
Loudness variability (dB)	189.92 (46.57)	175.50 (58.00)	1.74
Resonance (D_f, in Hz)	1298.84 (43.59)	1286.30 (45.02)	1.80
Resonance variability (Hz)	58552.55 (9290.43)	69778.38 (13480.89)	−6.16**

Note: Means for female and male speakers are given, with standard deviations in parentheses. f_0 = fundamental frequency; D_f = formant dispersion (lower values denote a more resonant, or less shallow-sounding, voice).
*$p < .05$. **$p < .01$.

covariance involving pitch and loudness). These effects were not qualified by speaker's sex, all *p*s > .11 (details of these analyses are available in the Supplemental Material).

Structural equation modeling using the acoustic cues standardized separately for male and female speakers produced identical results (see the Supplemental Material for details).

Experiment 2: Perceivers' Use of Cues for Hierarchy-Based Behavioral Inferences

In the next experiment, we turned from the cues-communicated side to the cues-utilized side of the lens model. Our goal was to assess whether perceivers use speakers' hierarchy-induced acoustic cues to make hierarchical inferences about speakers. Perceivers listened to recordings from Experiment 1 and made behavioral inferences about the speakers while blind to both condition and the fact that hierarchy was involved. Next, perceivers made dichotomous judgments of speakers' rank (i.e., high or low), which provided a measure of their objective accuracy in hierarchical identification. We conducted path analyses using the data from Experiment 1 and Experiment 2 to assess the role of the acoustic cues in mediating the link between speakers' rank and perceivers' behavioral inferences.

Hall et al. (2005) noted that a critical prerequisite to comparing effects of hierarchy on speakers' vocalizations and perceivers' inferences is operationalizing hierarchy similarly for speakers and perceivers. Therefore, for our dependent measures, we chose judgments of (a) concrete behaviors (rather than traits) that (b) are representative of people with high and low hierarchical rank, but do not strongly prime the concept of hierarchy, and (c) are relevant to negotiation situations.

Method

Perceivers. The perceivers in this experiment were 40 undergraduates (10 male, 26 female, 4 unidentified), who received credit toward a course requirement (see the Supplemental Material for further information on the perceivers). Sample size was determined in advance.

Procedure. Each perceiver listened to a subset of recordings of the Negotiation Passage from Experiment 1 (30 female and 30 male voices; see the Supplemental Material for details on the criteria used to select the speakers). After each recording, perceivers rated the speaker on 12 hierarchy-based behaviors plausible in a negotiation context (see Table 5), using a scale from 1 (*not at all*) to 7 (*very much*). Six of these behaviors were associated with high rank, and six with low rank. The order of the

Table 4. Results From Experiment 1: Adjusted Means for the Hierarchy-Based Acoustic Cues and Effect Sizes for Between-Condition Differences in These Means

Acoustic cue	High-rank condition	Low-rank condition	Effect of condition: η^2
Pitch (f_0, in Hz)*	158.61	155.52	.03
Pitch variability (Hz)*	1425.02	1648.37	.03
Loudness (dB)	59.34	58.67	.01
Loudness variability (dB)*	196.73	183.48	.03
Resonance (D_f, in Hz)	1129.39	1128.81	.00
Resonance variability (Hz)	42170.78	43654.54	.00

Note: Each mean was adjusted by its corresponding baseline acoustic cue. Asterisks indicate significant differences between the conditions (*$p < .05$).

Table 5. Items Used to Measure Hierarchy-Based Behavioral Inferences in Experiment 2

High rank	Low rank
How likely is it that this person is in a position to reward others?	Do you imagine this person as someone who works well in groups?
How focused do you imagine this person to be?	How good at following instructions do you imagine this person to be?
How effective do you imagine this person is at getting people to pay attention?	Do you imagine this person as someone who is attentive to the needs of others?
Do you imagine this person as someone who frequently interrupts others?	How uncomfortable at making direct eye contact do you imagine this person to be?
How demanding do you imagine this person to be?	Do you imagine this person as someone who has trouble speaking his/her mind?
Do you imagine this person as someone who expects to have his/her way with things?	Do you imagine this person as someone who is easily swayed by others?

speakers and the order of the behaviors were randomized for each perceiver. The low-rank behaviors were reverse-scored, and then scores for all 12 behaviors were averaged to create one composite hierarchical-inference score per perceiver per speaker (α = .92). After rating all the speakers, the perceivers listened to the voices a second time, in random order, and judged whether each speaker had been in a high- or low-rank role.

Results

Effect of condition on hierarchy-based behavioral inferences. We examined the extent to which perceivers' hierarchical inferences were consistent with the speakers' hierarchical rank using a 2 (speaker's condition: high rank, low rank) × 2 (speaker's sex: male, female) analysis of variance. We found only a main effect of speaker's condition, $F(1, 55) = 83.67$, $p < .001$ (all other ps > .22). Speakers who had been in the high-rank condition—regardless of their sex—were rated as more likely to engage in high-rank behaviors (M = 4.30, SD = 0.28) than were those in the low-rank condition (M = 3.45, SD = 0.42).

Table 6. Results From Experiment 2: Partial-Regression Slopes and Effect Sizes for the Relationship Between Hierarchy-Based Behavioral Inferences and Acoustic Cues

Acoustic cue	Slope	Effect size: η^2
Pitch (f_0)	0.014*	.10
Pitch variability (variance of f_0)	0.0000001	.00
Loudness	0.073**	.29
Loudness variability (variance of loudness)	0.004**	.14
Resonance (D_f)	−0.00004	.00
Resonance variability (variance of D_f)	0.0000001	.00

Note: Analyses controlled for baseline acoustic cues, speaker's sex, and speaker's condition. Asterisks indicate slopes significantly different from zero (*p < .05, **p < .01).

Accuracy of hierarchical-rank judgments. To analyze the dichotomous judgments of speakers' rank, we used a multilevel logistic regression procedure that allowed us to take into account individual differences in perceivers' accuracy, while appropriately dealing with dependency in the data (e.g., Ko et al., 2006). An accuracy score was assigned to each speaker-perceiver combination: 1 if the perceiver judged the speaker's power level correctly and 0 if the perceiver judged the speaker's power level incorrectly.[1] We then estimated a separate logistic regression model for each perceiver by regressing the perceiver's accuracy for the 60 speakers onto speaker's condition, speaker's sex, and their interaction. The resulting three partial-regression slopes (denoting the partial relationships between the three predictors and accuracy) were averaged across perceivers.

Perceivers were better than chance in assessing speakers' rank: Overall accuracy was significant, $F(1, 28) = 91.39$, $p < .001$. Accuracy did not differ as a function of speakers' rank (72% for low-rank speakers and 73% for high-rank speakers; $F < 1$), but was higher for male (75%) than for female (70%) speakers, $F(1, 28) = 5.90$, $p < .05$. The effect of speaker's sex was not qualified by condition ($F < 1$).

Effect of hierarchy-based acoustic cues. We assessed the impact of each acoustic cue on hierarchical inferences via six separate regression models, one for each cue. In each model, the behavioral inferences were regressed onto speaker's condition (1 = high rank; −1 = low rank), speaker's sex (1 = male; −1 = female), hierarchy-based acoustic variable (centered), and all possible two- and three-way interactions among these independent variables, covarying out the corresponding baseline acoustic variable. Table 6 presents the partial-regression slopes that represent the relationship between each of the hierarchy-based acoustic cues and behavioral inferences, controlling for the other variables.

There was a main effect of pitch, $F(1, 50) = 5.70$, $p <$ .05; perceivers associated higher pitch more strongly

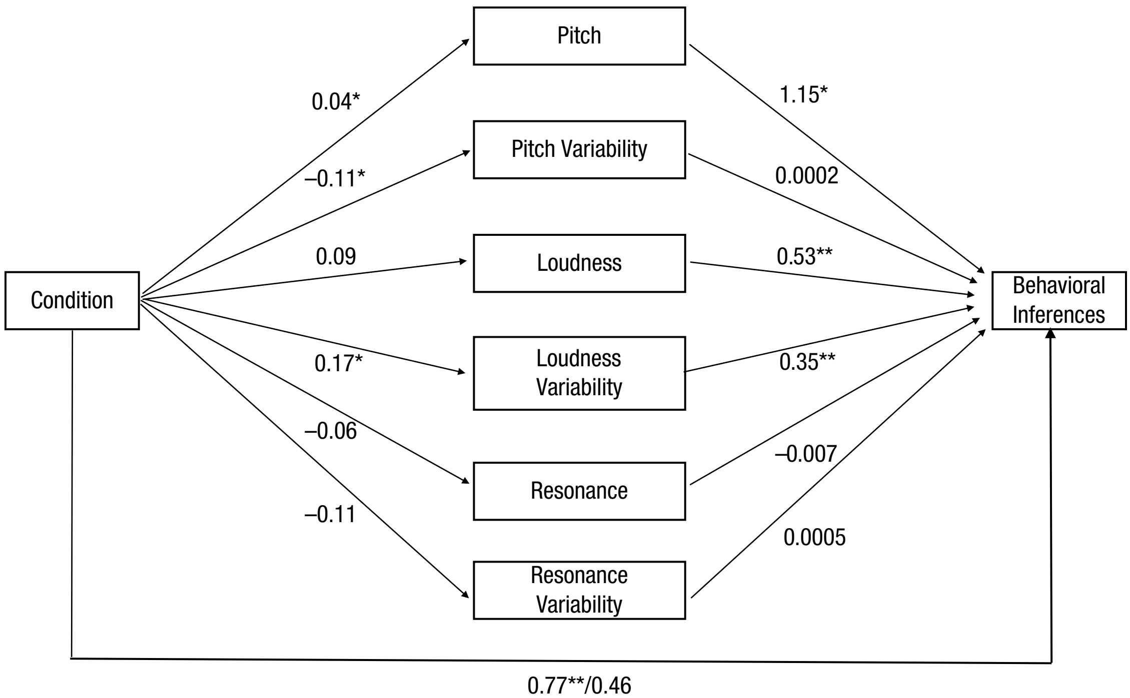

Fig. 2. Effect of hierarchy-based acoustic cues on accuracy of perceivers' behavioral inferences, controlling for baseline acoustic cues. The values shown are standardized partial-regression coefficients. In the analysis, speaker's sex and baseline acoustics were controlled for the paths from condition to acoustic cues, and speaker's condition, speaker's sex, and baseline acoustics were controlled for the paths from acoustic cues to behavioral inferences. Along the direct path at the bottom of the diagram, the value to the left of the slash is the coefficient obtained before controlling for the hierarchy-based acoustic cues and all two- and three-way interactions among these cues, speaker's sex, and speaker's condition; the value to the right of the slash is the coefficient obtained after these mediating variables were included in the model. Asterisks indicate significant coefficients (*$p < .05$, **$p < .01$).

with high- than with low-rank behaviors (ps > .20 for all other effects). Pitch variability yielded no significant effects (ps > .35), and none of the effects involving mean resonance or resonance variability were reliable (ps > .50). There was a main effect of loudness, $F(1, 50) = 20.54$, $p < .001$; perceivers associated louder voices more strongly with high- than with low-rank behaviors (ps > .25 for all other effects). Loudness variability also yielded a main effect, $F(1, 50) = 8.09$, $p < .01$; perceivers associated greater loudness variability more strongly with high- than with low-rank behaviors (ps > .35 for all other effects). Analyses using the mixed-model approach yielded an identical pattern of effects (see the Supplemental Material for details).

Achievement via the measured cues. We explored overall achievement in Brunswik's (1956) lens model by examining whether the relationship between speakers' actual rank and perceivers' behavioral inferences was mediated by speakers' acoustics. We subjected the data from Experiments 1 and 2 to a path analysis using the two-stage least-squares procedure. All analyses were conducted using unstandardized regression coefficients, as recommended by Kline (1998), but we present standardized betas from the path analysis in Figure 2. We also controlled for baseline acoustics. Recall that the relationship between speaker's condition and behavioral inferences, controlling for speaker's sex, was significant, $b = 0.77$, $F(1, 55) = 83.67$, $p < .001$. Controlling for the six hierarchy-based acoustic cues and all two- and three-way interactions among these cues, speaker's sex, and speaker's condition reduced this relationship to nonsignificance, $b = 0.46$, $F(1, 25) = 2.19$, $p > .16$ (see Fig. 2). Thus, the hierarchy-based acoustic differences exhibited by speakers partially mediated the correspondence between speakers' rank and perceivers' inferences.

We also explored an alternative mediation approach in which multiple mediators are estimated simultaneously via bootstrapping (Preacher & Hayes, 2008). Utilizing 5,000 bias-corrected bootstrapped samples, we estimated a model that included baseline acoustics, speaker's condition, speaker's sex, the interaction of speaker's sex and speaker's condition, and the interactions between speaker's condition and hierarchy-based acoustic cues. Results revealed a significant indirect effect (point estimate = 0.68, $SE = 0.31$, 95% bias-corrected confidence interval = [0.19, 1.43]), showing that hierarchy-based acoustics mediated the correspondence between speakers' rank and perceivers' inferences. The same pattern of results was obtained using a noninteractive model. (See the Supplemental Material for indirect effects of all six acoustic cues in the interactive model and for details of a third mediation analysis.)

Replication Experiment

We also conducted a replication experiment using all the voices from Experiment 1. The results replicated those from Experiment 2 (see the Supplemental Material for details on the method and results).

General Discussion

The current experiments provide the first look at the relationship between hierarchy and acoustics using the framework of Brunswik's (1956) lens model. On the left side of the lens, we found that the voices of speakers placed in high rank were higher pitched, less variable in pitch, and more variable in loudness than the voices of speakers in low rank. On the right side of the lens, speakers whose voices were higher pitched, were louder, and had greater loudness variability were perceived as more likely to be high ranked. Thus, there was consistency between the left and right sides of the lens for all but two of the acoustic cues, which demonstrates that there was a match between how hierarchy affected speakers' acoustics and the acoustics perceivers used to perceive the hierarchical rank of speakers.

Brunswik's (1956) lens model highlights the importance of considering distal and proximal cues (see the Supplemental Material for details). This point is relevant to our results for pitch variability and loudness. Rank affected pitch variability, but perceivers did not use this cue to infer rank. In contrast, perceivers used loudness to infer rank, but rank did not affect speakers' loudness. One possible explanation is that the distal cue change in pitch variability may have produced the proximal cue change in loudness, which helped perceivers achieve accuracy. Another way to think about this is that individual cues with low correspondence between the left and right sides of the lens can contribute to accuracy as much as high-correspondence cues do.

Our results for pitch may seem counterintuitive given previous findings that greater dominance is associated with lower pitch. It is crucial to bear in mind, however, that in our study, dominance-based pitch was removed by controlling for individual differences in baseline pitch. Thus, our results concern within-speaker change in pitch that was independent of individual differences in baseline pitch. There is no reason for dominance-based acoustics to resemble hierarchy-based acoustics. Indeed, a number of previous studies have also demonstrated a positive relationship between pitch and verticality (e.g., Scherer et al., 1973; Tusing & Dillard, 2000).

The largest vocal sexual dimorphisms that are manifest in speakers and detected by perceivers are pitch and resonance (Puts et al., 2012). As we have discussed, past work suggests that these cues relate to hierarchy distinctly from the way they relate to dominance. Our results provide important preliminary empirical evidence that this is the case, as the pattern of association between these cues and hierarchy differed from the previously found association between these cues and dominance.

Researchers have suggested that power is associated with positive emotions (Keltner, Gruenfeld, & Anderson, 2003), and one of the acoustic markers of positive affect is increase in fundamental frequency (e.g., Banse & Scherer, 1996; Johnstone & Scherer, 2000). This provides a plausible explanation for why higher rank may be associated with higher pitch. In contrast, there is no reason to expect dominance to be correlated with affect.

Why were perceivers more accurate at judging male than female speakers' rank? We note that men are more likely to be in high-rank positions compared with women. Consequently, it may be easier for men to assume high-rank roles because they have had more experience with such roles. This logic suggests that the difference in accuracy for male and female voices might have been more pronounced in the high- than the low-rank condition. Although the interaction of speaker's sex and speaker's condition was not significant, we tested for a main effect of speaker's sex separately in each condition and confirmed our reasoning: Accuracy for speakers in the high-rank condition was significantly higher for male speakers (77%) than for female speakers (69%), $F(1, 28) = 5.11$, $p < 05$. In contrast, accuracy for speakers in the low-rank condition did not differ between male speakers (74%) and female speakers (71%), $F < 1$. Thus, the effect of speakers' sex on perceivers' accuracy may reflect males being more adept in high-rank roles than females are (see the Supplemental Material for additional discussion).

The change in Margaret Thatcher's voice after she received voice coaching provides an interesting real-world analogue to our results. (Two voice clips illustrating this change were showcased in a program on Public Radio International titled "The Sound of Leadership"—see Gallafent, 2008.) Thatcher went through extensive voice coaching designed to help her present a more powerful persona after she became the United Kingdom's prime minister. Her pitch, loudness variability, and resonance variability increased, and her pitch variability decreased after the coaching she received after becoming prime

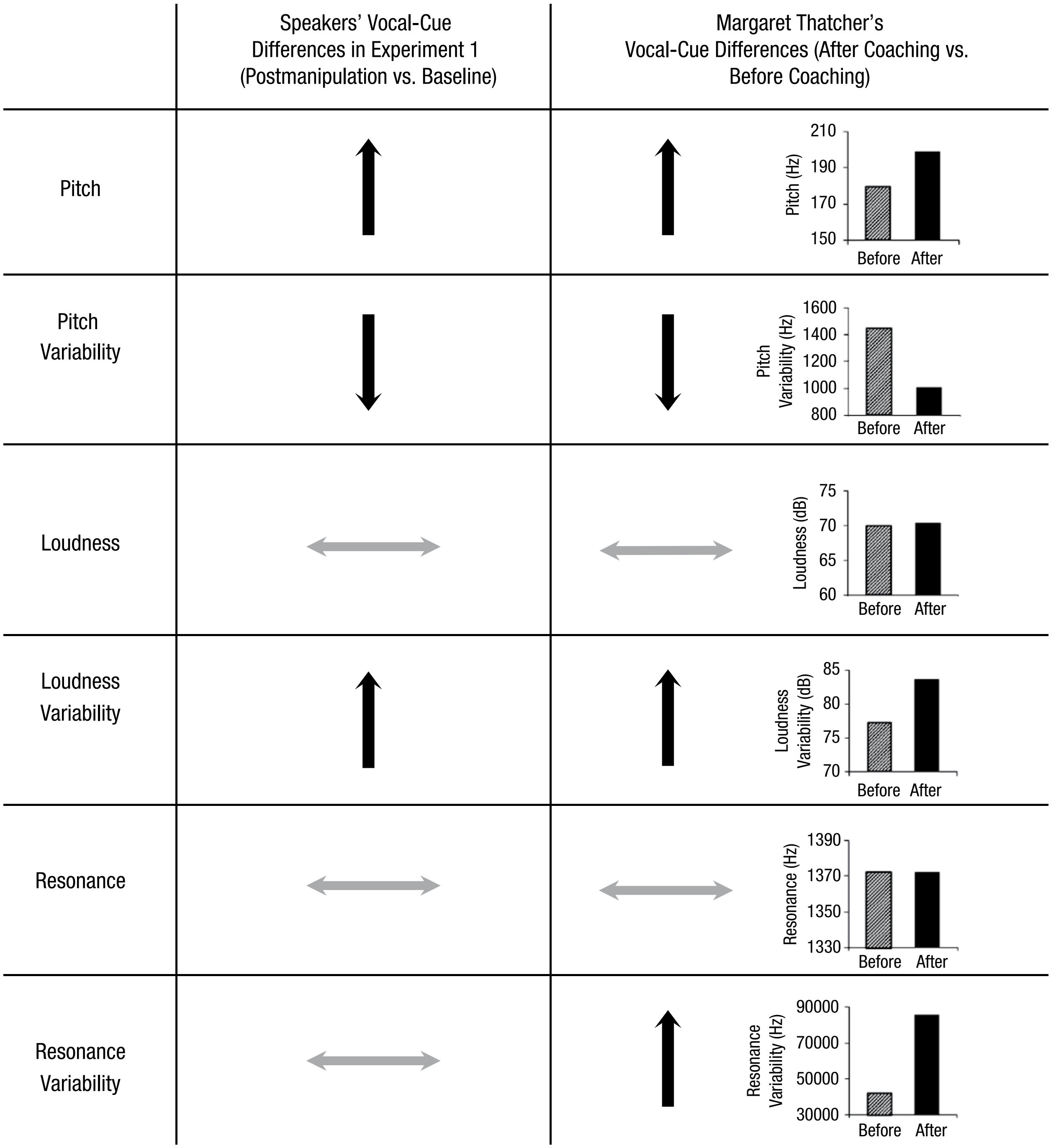

Fig. 3. Changes in speakers' acoustic cues after the hierarchy manipulation in Experiment 1 and changes in Margaret Thatcher's acoustic cues after she received voice coaching intended to help her present a more powerful persona. For Experiment 1, a black arrow indicates that the hierarchy-based change in the cue was greater for high- than for low-rank speakers, and a gray arrow indicates that there was no reliable change in the acoustic cue as a function of rank; the direction of the arrows indicates the direction of the difference between high-ranked and low-ranked speakers (high-ranked minus low-ranked). For Thatcher, a black arrow indicates the direction of change in a vocal cue after voice coaching, and a gray arrow indicates that the vocal cue was similar before and after coaching.

minister. Although this is a single real-world example, it seems remarkable that our untrained speakers' momentary vocal changes were practically identical to the changes observed in someone who was trained to express authority in her voice (see Fig. 3; additional details are available in the Supplemental Material).

Future directions

In this first exploration of the effects of hierarchy on voice, we focused on individuals to maintain tight experimental control. Because hierarchy is a dyadic and group phenomenon, future research should investigate whether the same effects occur in dyads and groups. Also, because this research was conducted in the United States, we do not know the extent to which our findings generalize to other cultures, especially those in which hierarchy is conceived, conceptualized, and emphasized differently than it is in U.S. culture. Consequently, future research should test whether these findings can be replicated in other cultures.

Cadenza

The sound of hierarchy is indeed distinctive. People may attempt to control their words and posture to convey a desired rank, but amidst the chaotic signals of hierarchy, the voice may be the one window that affords a clear view.

Author Contributions

S. J. Ko developed the study concept. S. J. Ko and A. D. Galinsky came up with the study design, and M. S. Sadler provided input at certain points. Testing, data collection, analyses, and interpretations were performed by S. J. Ko and M. S. Sadler. S. J. Ko and A. D. Galinsky drafted the original manuscript and subsequent revisions. M. S. Sadler provided critical comments. All authors approved the final version of the manuscript for submission.

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The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

Open Practices

All data and materials have been made publicly available via Open Science Framework and can be accessed at https://osf.io/cw6y8/?view_only=24a186cebd52441ea0170ed63caf70ab and https://osf.io/5hzv9/?view_only=94aa2b0312c3463493ca6f61c5fc3811, respectively. The complete Open Practices Disclosure for this article can be found at http://pss.sagepub.com/content/by/supplemental-data. This article has received badges for Open Data and Open Materials. More information about the Open Practices badges can be found at https://osf.io/tvyxz/wiki/view/ and http://pss.sagepub.com/content/25/1/3.full.

Note

1. Eleven perceivers' data were unusable because they showed no variance in their judgments. When we included these 11 participants, accuracy was 66% for low-rank and 67% for high-rank speakers.

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