Voice pitch modulation in human mate choice

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Abstract

Inter-individual differences in human fundamental frequency (*F*0, perceived as voice pitch) predict mate quality, reproductive success, and affect listeners' social attributions. Although humans can readily and volitionally manipulate their vocal apparatus and resultant voice pitch, for instance in the production of speech sounds and singing, little is known about whether humans exploit this capacity to adjust the nonverbal dimensions of their voices during social (including sexual) interactions. Here, we recorded full-length conversations of thirty adult men and women taking part in real speed dating events, and tested whether their voice pitch (mean, range, and variability) changed with their personal mate choice preferences and the overall desirability of each dating partner. Within-individual analyses indicated that men lowered the minimum pitch of their voices when interacting with women who were overall highly desired by other men. Men also lowered their mean voice pitch on dates with women they selected as potential mates, particularly those who indicated a mutual preference (matches). Interestingly, although women spoke with a higher and more variable voice pitch toward men they selected as potential mates, women lowered both voice pitch parameters toward men who were most desired by other women and whom they also personally preferred. Between-individual analyses indicated that men in turn preferred women with lower-pitched voices, wherein women's minimum voice pitch explained up to 55% of the variance in men's mate preferences. These results, derived in an ecologically valid setting, show that individual and group-level mate preferences can interact to affect vocal behaviour, and support the hypothesis that human voice modulation functions in nonverbal communication to elicit favourable judgments and behaviours from others, including potential mates.

Keywords: mate choice, sexual selection, speed dating, nonverbal communication, fundamental frequency, vocal control

The human voice conveys evolutionarily and socially relevant information that affects the outcomes of mate choice and intrasexual competition. To date, most research in this area has focused on men, whose fundamental frequency (*F*0, perceived as pitch) appears to have been shaped by sexual selection to communicate masculinity, physical formidability, and genetic quality [1]. Men with low-pitched voices typically have higher levels of pubertal [2] and circulating [3,4] testosterone, and are perceived as more masculine and dominant than are men with higher-pitched voices [5 for review]. Low pitch variability, perceived as a monotone voice quality, also predicts men's formidability [6]. In turn, a large literature demonstrates that women generally prefer men with relatively low-pitched voices, particularly in the context of a short-term relationship, and that such men report more sexual partners and have more offspring than their higher-pitched counterparts [7]. In fact, men with low-pitched voices tend to have higher success in a range of social contexts, from mating to socioeconomic and political [5,7].

Among women, between-individual differences in voice pitch are understudied, but appear to indicate reproductive status (e.g., pre-pubertal and post-menopausal stages of fertility) and sexual receptivity [7,8]. Women with relatively high-pitched voices are typically perceived as more feminine, younger, and more attractive than are women with low-pitched voices [9–12]. However, several studies suggest that a lower pitch in women is perceived as attractive or 'sexy' [13–16], while others fail to identify any relationship between female voice pitch and judgments of attractiveness [6]. In contrast, women with low-pitched voices are consistently judged as more dominant, competent, and mature, and as better leaders than women with a higher voice pitch [12,17,18]. The trade-off implied by this dichotomy suggests that women may

volitionally raise their voice pitch to signal youth and femininity, but lower their pitch in contexts where they wish to be taken seriously, or to indicate sexual interest to a listener (see e.g., [13]).

Low frequency vocalisations signal dominance, not only in humans, but in a wide range of animals. Many species vocalise with a lower voice pitch during agonistic interactions, thereby communicating aggression and threat, and in some species (e.g., red deer *Cervus elaphus,* and koalas *Phascolarctos cinereus*), males extend the length of their vocal tract by lowering their larynx (and thus their formant frequencies), thereby portraying a larger body size to other males in competitive contexts, as well as to potential female mates [19,20]. Importantly, such frequency changes observed in the calls of most nonhuman mammals, including primates, typically occur in response to physiological or environmental triggers. Humans, in contrast, are readily capable of volitionally (i.e., voluntarily) manipulating their vocal apparatus, owing to increased neural control [21,22]. Perhaps the most common form of volitional voice modulation in humans involves manipulating the articulators, including the lips, tongue and jaw, to produce different vowel sounds in articulated speech [23]. We can also actively modulate the pitch of our voices by adjusting the tension and the effective length of the vocal folds, or by increasing sub-glottal pressure (i.e., air flow from the lungs)[24]. Pitch modulation is important for intonation, prosody, and emotional expression, and is also observed in acting and singing [22,25].

Although the capacity for voice pitch modulation in speech production is well documented, whether humans exploit this capacity to adjust the *nonverbal* dimensions of their voices during social interactions has not yet been systematically investigated.

The ability to volitionally change the pitch of our voice may be evolutionarily advantageous. During social and sexual communication, such vocal modulation could function to honestly communicate one's motivations and emotions, but may also be used to favourably manipulate the perceptions and behaviours of others, including potential mates [22]. Indeed, men and women can volitionally lower their voice pitch when instructed to sound more masculine [26] or physically larger [27], and both sexes modulate their pitch when instructed to sound confident, dominant and intelligent [14]. Thus, not only are humans capable of vocal control 'on demand', but also of fine-tuning voice modulations to mimic real or perceived associations between physical and psychological traits of a speaker and their voice.

Studies examining voice modulation in mating contexts have, to date, only been conducted in the laboratory using widely varied methodologies, and have produced mixed results [13,28–31]. Some studies have found that men speak with a lower and less variable voice pitch [13,29] or a lower minimum voice pitch [31], whereas others report an increase in men's mean pitch and pitch variability [28,31] when speaking with a hypothetical female mate. Likewise, women have been shown to either increase [30], decrease [13,14], or not alter their voice pitch [31] when speaking to hypothetical male mates. In these studies, dating contexts were mocked (e.g., participants were asked to leave a voice message for an unknown person whose photo or video they viewed), and the attractiveness of hypothetical dating partners was either not controlled or was pre-rated by another group of participants.

Here, we recorded the voices of thirty adult men and women (aged 20-40) taking part in real speed dating events, and examined within-individual changes in their voice pitch

parameters as a function of their date's overall desirability (i.e. number of successful speed dates), and importantly, their own personal mate choice preference for each dating partner. The present study is the first to examine human voice modulation in a real-world mate choice scenario. With this high degree of ecological validity and multiple mate preference measures (individual and group-level), this study addresses limitations of past work that likely contributed to inconsistent findings.

METHODS

Participants

Thirty participants were recruited by a professional speed dating company via posters and online adverts announcing local speed dating events for single men and women aged 20 to 40. Participants were then assigned to one of two age groups to limit age differences between dating partners, as is typical in speed dating. Ages ranged from 20 to 33 in the younger group (mean 22±1.7 in women, 28.3±1.0 in men) and 25 to 40 in the older group (mean 29±4.1 in women, 29.0±5.6 in men). Although men were on average 3.5 years older than women (28.5 vs 24.9 years), the age difference between pairs in speed dates averaged less than a year (0.07±6.9 years) and was not significantly different from zero (t_{213}=-.137, p=.89). Before confirming their participation, interested individuals were informed that their voices would be recorded during the event for subsequent acoustic analysis as part of a research study. All participants provided signed consent before taking part in the study.

Questionnaires completed after the event confirmed that all participants were single. The reported amount of time since a previous relationship ranged from 1 to 60 months and did not differ significantly between the sexes (mean 19.3 months among women, 11.9 months among men; t_{24}= 1.08, p=.29). Half of the women, and one-quarter of the men, reported not previously having participated in a speed dating event. Among those who had, participation rates ranged from 1-2 (women) and 1-15 (men). Men in our sample therefore reported greater experience with speed dating than did women (t_{26}= -2.34, p=.03, equal variances not assumed).

Procedure

We held two speed dating events co-organised and co-directed by an experienced speed dating host, held in a dedicated room at a local café. Participants arrived individually to the café where they were greeted by the host and researchers. Upon arrival, the host explained the speed dating procedures to participants in small groups, and each participant was given a nametag and booklet in which to mark their personal mate choice preferences after each speed date (i.e., 'yes' or 'no'). After providing informed consent, participants were fitted with a portable voice recorder and headset and seated at one of several designated tables.

Following typical speed dating procedures, each dating round lasted 6 minutes after which men rotated to an adjacent table. During the brief interlude between dates, both sexes indicated their preference for their previous date in a personalized booklet by marking 'yes' or 'no' beside that date's ID. This process continued until all men and women had dated one another. Following the final round, participants were given additional time to indicate their mate choice preferences. As is customary at speed

dating events, participants who were 'matched' (i.e., who indicated a mutual preference for one another) were informed by email within 24 hours and given one another's contact information. Participants also completed a short questionnaire after the event, in which they indicated their age, sex, and were asked to provide demographic information and details regarding previous speed dating experience.

Acoustic recording and analysis

Participants' voices were recorded throughout the entire duration of the speed dating event using portable Tascam DR-05 recorders and lightweight (12 g), discreet cardioid condenser headset microphones at a sampling rate of 96 kHz and 24-bit amplitude quantization. Recordings were stored onto microSDHC media cards as uncompressed WAV files and later transferred to a laptop computer for editing and analysis. This method allowed us to obtain high quality, directional voice recordings that would otherwise be difficult to obtain in a noisy environment using a stationary microphone.

Acoustic editing and analysis were performed in Praat v. 6.0.21 [32]. Fragments of silence, acute noise, nonverbal vocalizations (e.g., laughter) and multi-voicing (e.g., the voice of the dating partner) were first manually removed from audio files. Recordings were then segmented into multiple parts each corresponding to a given participant and a single speed date. We further split each sound file into three equal time segments (beginning, middle and end of the date; mean segment duration 50.6±23 s), resulting in a total of 726 voice clips for acoustic analysis.

We used a batch-processing script to measure five parameters of fundamental frequency: mean (*F*0 mean), range (*F*0 min and *F*0 max), variability and contour,

including standard deviation (*F*0 *sd*) and the coefficient of variation (*F*0 *CV;* given by *F*0 *sd*/*F*0 mean [33]). All *F*0 parameters were measured using Praat's autocorrelation algorithm with a search range of 60-600 Hz and a time step of 0.01 s. Spurious octave jumps were manually corrected (see [34]). Perceptually, *F*0 mean, min and max represent the average, lower and upper ranges of a speaker's voice pitch, respectively, with relatively lower values sounding 'deeper'. In contrast, *F*0 *sd* represents the absolute degree of voice pitch variability around the mean across an utterance, and *F*0 *CV* adjusts this variation to the magnitude of *F*0 thereby controlling for the nonlinear perception of voice pitch. Thus, *F*0 *CV* more reliably represents the perceptual salience of this *F*0 variability.

Preference scores

We computed three types of preference score for each participant. *Desirability scores* represent how 'desired' the participant was by others, and were computed by dividing the number of dates who marked the participant as 'yes' by the total number of dates, giving the proportion of dating partners who indicated a preference for the participant. *Choosiness scores* represent how 'choosy' the participant was, and were computed by dividing the number of dates whom the participant marked as 'yes' by the total number of dates. Finally, *match scores* indicate the number of two-way preferences, that is, the number of dates on which both participants indicated a mutual preference for one another.

Statistical Analysis

We used linear mixed models (LMMs) with maximum-likelihood estimation to test for within-individual variation in *F*0 parameters (voice pitch modulation). We ran separate

models for each sex due to non-independence in female and male data (pairing in speed dating), and because vocal parameters and preferences differ between the sexes.

We examined *F*0 modulation as a function of the personal mate choice preferences of both dating partners (i.e., indicating one another as a 'yes' or 'no'), the speaker's overall choosiness score, and the date's overall desirability score. Preference variables were included as fixed factors (*chose date*, the participant marked that respective date as a 'yes'; *chosen by date,* the date marked the participant as a 'yes') or fixed covariates (*choosiness score of speaker; desirability score of date*). *Participant identity* was included as a random subject variable in all models, and the *age difference* between each man and woman on each speed date was included as a random covariate. We additionally included *time segment* as a fixed factor to examine whether voice changes were more likely to occur at the beginning, middle or end of a date. These factors were first examined in a fully factorial model. There were no main or interaction effects of *choosiness score of speaker* on vocal parameters for either sex, therefore this variable was excluded from the final models. *Time segment*, although not significant, was retained in final models to avoid pseudo-replication; its inclusion did not affect the pattern of results. The final model can be described with the equation:

$$y_{ij} = \left(b_0 + u_{0j}\right) + \ b_1 X_{ij} + \ b_2 X_{ij} + b_3 X_{ij} + b_4 X_{ij} + \left(b_5 X_{ij} + u_{5j}\right) X_{ij} + \epsilon_{ij}$$

Note: b_1 – chose date; b_2 – chosen by date; b_3 – time segment; b_4 – date's overall desirability; b_5 – *age difference* between each man and woman on each speed date; u_{0j} – a component to the intercept measuring variability in intercepts; u_{5j} – a component to the slope of the overall model that measures the variability in slopes

Following this, we examined significant main effects of categorical variables in the LMM using pairwise tests with Šidák correction for multiple comparisons, and examined significant main effects of, or interactions with, continuous variables (i.e., date's desirability) using linear regression to illustrate the direction and strength of these relationships. For interactions between continuous covariates and fixed factors, we averaged vocal parameters within each relevant fixed category (e.g., chose date, did not choose date,) and plotted separate lines of best fit for each fixed factor.

Sex differences, effects of participant age, or effects of the age difference between dating pairs on choosiness, desirability and match scores or on personal mate choice preferences were tested using one-way analyses of variance or linear regression. All tests were two-tailed at an alpha level of .05.

RESULTS

Desirability, choosiness, and matches

We found that women were on average significantly choosier than men ($F_{1,29}$ = 6.74, p=.01): while women indicated a preference for 30% (range 0-67%) of their dates, men indicated a preference for 51% (range 13-88%). In turn, women's desirability scores were significantly higher than men's ($F_{1,29}$ = 6.72, p=.01), averaging 52% in women (range 0-91%) compared to 28% in men (range 0-67%). Both partners indicated a mutual personal preference for one another on 14% of dates; individual success rates for matches ranged from 0% (no match) to 33% (women) and 38% (men), and did not differ significantly between the sexes ($F_{1,29}$ = 0.61, p=.81). Desirability and choosiness

scores correlated negatively in both sexes, however this relationship only reached statistical significance among women (r = - .60, p = .03; men: r = - .24, p = .35), indicating that women who were more desirable were also choosier.

Participant age did not significantly predict desirability scores (men: $F_{1,16}$=1.7, p=.21; women: $F_{1,11}$=3.8, p=.08), choosiness scores (men: $F_{1,16}$=.05, p=.82; women: $F_{1,11}$=4.4, p=.06), or match scores (men: $F_{1,16}$=.38, p=.55; women: $F_{1,11}$=.004, p=.95) in either sex, though older women showed nonsignificant trends toward lower desirability scores, and higher choosiness scores, compared to younger women.

Voice pitch modulation

Linear mixed models (LMMs) tested for within-individual changes in voice pitch parameters across speed dates (see Statistical Analysis). Table 1 reports significant effects of models conducted separately for each sex.

Table 1. **Within-individual *F*0 modulation.** Linear Mixed Models examining relationships among speed dating preferences, date's overall desirability, and within-individual modulation of voice pitch parameters in women's and men's voices, controlling for the age difference between dating partners. Only significant (p<.05) effects are reported here, for full model outputs and estimated marginal means see Tables S1 and S2. Model syntax is provided in supplemental materials. See also Figure 1.

Voice parameter	**Model source**	df_1, df_2	***F***	***p***
	Women			
*F*0 mean	Intercept	1, 321	9411.2	<.001
	Chose date	1, 321	18.7	<.001
	Date's desirability	1, 321	19.1	<.001
	Chose date * Date's desirability	1, 321	9.8	.002
*F*0 min	Intercept	1, 321	595.2	<.001
	Chosen by date	1, 321	4.6	.034
*F*0 max	Intercept	1, 321	6237.0	<.001
	Chose date	1, 321	4.0	.047
*F*0 *sd*	Intercept	1, 321	1571.9	<.001
	Chose date	1, 321	16.4	<.001
	Date's desirability	1, 321	14.8	<.001
	Chose date * Date's desirability	1, 321	6.9	.009
*F*0 *CV*	Intercept	1, 321	2013.1	<.001
	Chose date	1, 321	7.0	.009
	Date's desirability	1, 321	5.5	.02
	Chose date * Chosen by date * Date's desirability	1, 321	3.9	.048
	Men			
*F*0 mean	Intercept	1, 321	1089.6	<.001
	Chose date	1, 321	4.6	.033
	Chose date * Chosen by date * Date's desirability	1, 321	4.4	.036
*F*0 min	Intercept	1, 321	633.0	<.001
	Date's desirability	1, 321	6.6	.01
*F*0 max	Intercept	1, 321	340.2	<.001
*F*0 *sd*	Intercept	1, 321	173.2	<.001
*F*0 *CV*	Intercept	1, 321	257.9	<.001

Women modulated their average voice pitch (*F*0 mean), maximum voice pitch (*F*0 max), and pitch variability (*F*0 *sd* and *CV*) as a function of their personal mate choice preferences across speed dates (Fig 1a). Pairwise tests with Šidák correction showed that, overall, women spoke with a significantly higher *F*0 mean ($p < .001$, $df = 321$, 95% CI for difference = 6.5 to 19.3) *F*0 max ($p = .01$, $df = 321$, 95% CI = 4.2 to 36.5), and *F*0 variability (*F*0 *sd*, $p < .001$, $df = 321$, 95% CI = 4.0 to 11.5; *F*0 *CV*, $p = .006$, $df = 321$, 95% CI = .005 to .029) toward men they chose as potential mates (marked as "yes") than toward men they did not choose (marked as "no"). The average magnitude of women's mean voice pitch modulation (13 Hz) exceeds perceptual discrimination thresholds by almost three-fold [9].

However, these main effects were qualified by interactions between women's personal mate choice preferences and men's overall desirability scores. As illustrated in Figure 1b, women raised the *F*0 mean and absolute variability (*F*0 *sd*) of their voices on dates with men they personally preferred, but only toward men with desirability scores below 0.50 (i.e., men chosen by fewer than half of their dating partners), for whom women raised their pitch by more than 20 Hz on average. In contrast, women marginally lowered these pitch parameters toward men they preferred and whose desirability scores were among the highest. On dates with men they preferred, 14% and 12% of the modulation in women's *F*0 mean and *F*0 *sd* was explained by the man's desirability score, respectively, whereas the desirability of non-preferred men did not predict women's voice pitch modulation (Fig 1b). While women spoke with a less monotone voice (higher *F*0 CV) toward men they preferred, the magnitude of this voice change also decreased as men's overall desirability increased, and was absent on dates

in which neither the woman nor the man showed a personal preference for one another.

Variation in women's minimum pitch was not qualified by the date's overall desirability nor women's own preferences, but rather was predicted solely by men's preferences. Women spoke with a lower *F*0 min on dates in which their dating partner chose them, lowering their *F*0 min by an average of 15.8 Hz compared to dates on which they were not chosen (p = .007, df = 321. 95% CI = -27.3 to -4.3; Fig 1a).

Men also modulated their voices across speed dates. Although the LMM indicated that men spoke with a lower *F*0 mean toward women they chose (marked as "yes") than toward those they did not choose (Table 1), pairwise tests showed that this main effect did not reach significance following Šidák correction (p = .26, df = 321, 95% CI for difference = -11.0 to -2.9; Fig 1c). Indeed, like women, this effect was qualified by a significant interaction, indicating that men lowered their *F*0 mean more toward women with low than high desirability scores, and only on dates with women they chose as potential mates, particularly if those women chose them in return (Fig 1d). Indeed, men lowered their *F*0 mean by more than 20 Hz, or approximately four times the just-noticeable difference, toward 'matched' women whose desirability scores were among the lowest. Like female participants, the desirability of non-preferred women did not predict men's mean voice pitch modulation (Fig 1d). Linear regression further showed that men lowered their *F*0 min when speaking to women with relatively higher overall desirability scores, regardless of personal preference (Fig 1c).

In addition to controlling for *age difference* in LMMs, we ran additional analyses of variance that confirmed that the age difference between sexes in each speed dating pair did not significantly predict the mate choices of either sex in either age group (younger women: $F_{1,76} = 0.02$, $p=.90$, older women: $F_{1,29} = 1.18$, $p=.29$; younger men: $F_{1,76} = 3.74$, $p=.06$, older men: $F_{1,29} = 0.51$, $p=.48$). Moreover, our LMM showed no significant effect of time segment on voice pitch modulation (Table S1), indicating that pitch modulation emerged early in the speed date and persisted at a similar magnitude throughout.

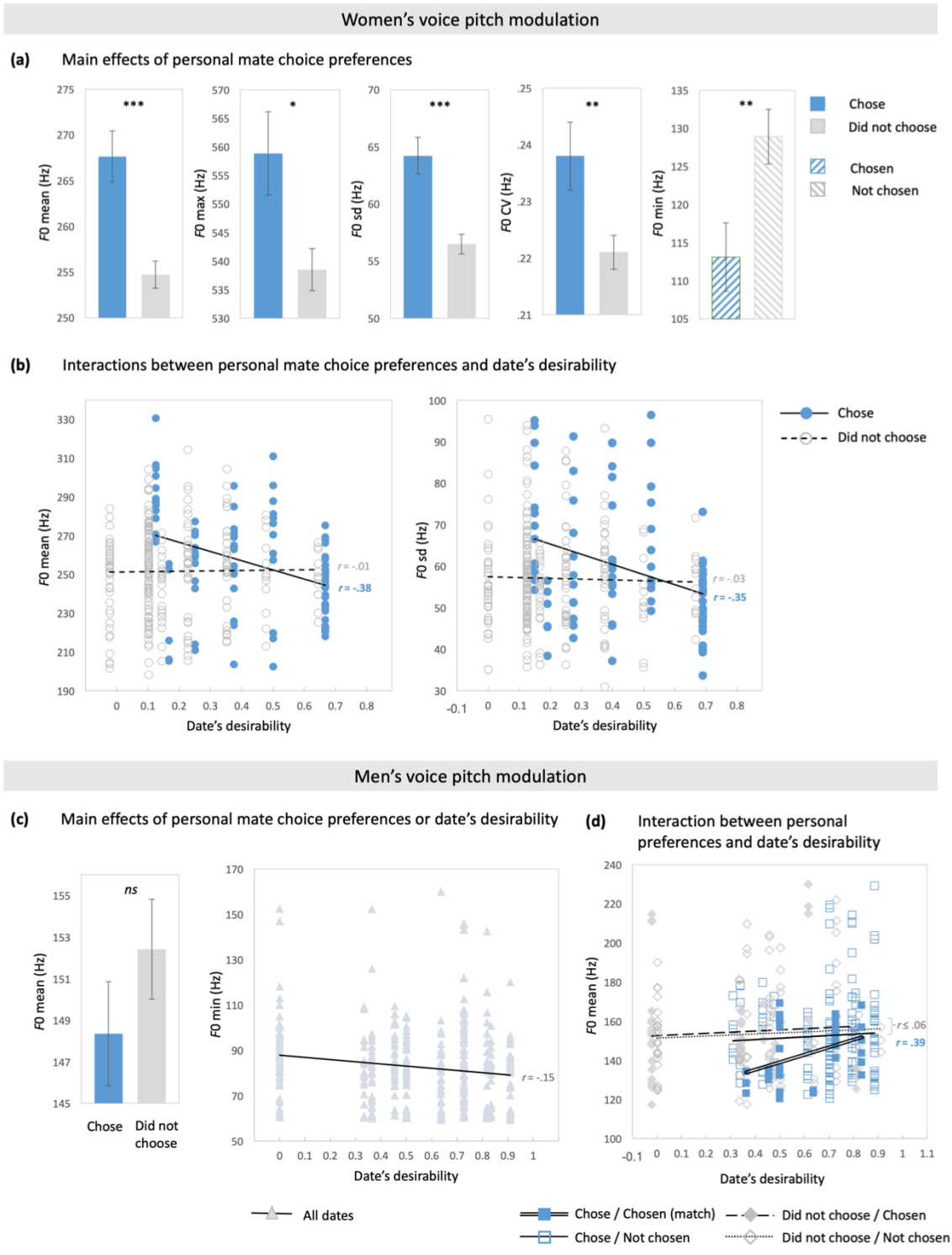

Figure 1. Women's and men's *F*0 modulation across speed dates. Panels (a) and (c) show main effects of personal mate choice preferences on voice pitch modulation, whereas panels (b) and (d) show interactions between personal preferences and date's overall desirability. Columns in bar graphs represent estimated marginal means from LMMs (see Tables 1 and S2), where error bars represent standard errors of the means. Markers in scatterplots represent individual speed dates; markers for distinct categories are minimally offset along the x-axis to avoid overplotting and to improve visualisation. Asterisks' indicate statistical significance of pairwise comparisons following Šidák correction, where *** $p<.001$, ** $p<.01$, *$p<.05$, and ^{ns} $p>.05$. Correlation coefficients (r) are given beside each linear regression line. See embedded legend for additional details.

Relationships between voice pitch and desirability or choosiness

In addition to examining within-individual fluctuations in voice pitch (that is, how participants modulated their voices from date-to-date), we tested whether between-individual differences in pitch predicted desirability and choosiness scores. Average pitch parameters were computed for each participant by averaging *F*0 parameters across all dates, within-individuals, and regressed against their overall desirability and choosiness scores.

We found that women's *F*0 min explained 43.7% to 55% of the variance in their desirability scores (r = -.66, p = .014, n =13), indicating that women with lower pitch minima were more desired by men. The strength of this relationship increased after controlling for women's choosiness scores (r_p = -.74, p = .006, df = 10). Although relationships between women's desirability and their *F*0 mean (r_p = -.45) and *F*0 CV (r_p = .37) were moderate in strength, no other voice pitch parameter explained a significant amount of variance in the desirability or choosiness scores of either sex (Table S3).

DISCUSSION

The results of this study support the hypothesis that women and men modulate their voices in real-life mate choice contexts based on personal mate choice preferences, and the mate quality of a potential partner. Women spoke in a higher-pitched and less monotone voice on speed dates with men they chose as potential mates, however only if those men also had a relatively lower overall desirability score (i.e., were preferred by fewer than 50% of other women). Men lowered their mean pitch on dates with

women they personally preferred, but here too, the magnitude of men's voice pitch modulation decreased as their dates' overall desirability increased.

Previous studies examining voice modulation in mock dating contexts have produced conflicting results [13,28–31], possibly because dating partners were hypothetical, and their desirability was based solely on pre-rated attractiveness of photos or videos rather than on participants' personal preferences. Here, we show that personal mate choice preferences can deviate from, interact or even conflict with group-based desirability scores. Indeed, although women generally spoke with a higher pitch (in line with [30]), and men with a lower pitch (in line with [13,31]), toward dating partners they marked as 'yes', this was driven largely by dating partners with lower desirability scores, toward whom both sexes altered their voice pitch by more than 20 Hz (1.5 semitones in women, 2.7 in men) on average. In fact, women spoke with a lower voice pitch toward men who were both highly desired by other women and whom they personally preferred. This finding supports at least two other studies [13,14] that report that women lower, rather than raise, their voice pitch in a mating context, and thus highlights the need to consider both group-level and individual mate preferences in future work.

A large body of research indicates that men with relatively low-pitched voices are preferred by women as mates and have high mate value [5,7]. Thus, the observation that men lowered their voice pitch in response to women they preferred, particularly if those women also preferred them, suggests that voice modulation in men may function to increase their reproductive success. In contrast, our results contradict the prediction that women ubiquitously feminize their voices toward preferred potential mates, as

this was not the case on dates with highly desirable men. Moreover, in our sample of speed daters, women spoke with lower pitch minima toward men who preferred them, and when comparing across women, men preferred women who spoke with a lower minimum pitch, such that women's minimum pitch explained up to 55% of the variance in how desired they were by men.

This apparent conflict between the functional relevance of high versus low voice pitch in women may be resolved by considering that indexical cues to static speaker traits (e.g., age, sex) may function differently than more dynamic, social or sexual cues. Thus, while a relatively high voice pitch in women can signal youth, femininity and reproductive fecundity [7], by dynamically lowering her voice pitch a woman might be signalling sexual interest and intimacy to a man [13–15]. Alternatively, or simultaneously, she might lower her pitch to communicate social dominance or a confident and mature persona, as people with low-pitched voices are often attributed traits such as competence, trustworthiness and leadership [5,17]. Indeed, recent studies suggest that young women are increasingly using a very low pitch register, resulting in vocal fry or a 'creaky' quality, in professional work contexts [35,36].

Dynamic voice modulation may be especially functional when multiple modalities are available to the receiver, as they were in our study and typically are in social interactions. In a mating context, for instance, a man may gauge a woman's age, femininity, and fecundity from visual and olfactory cues [37], while simultaneously interpreting social and sexual information from the dynamic properties of the woman's voice. While it is possible that a woman's age may influence the direction and degree to which she modulates her voice pitch toward potential mates, our results showed no

effect of age, or age differences between dating partners, on voice modulation. Age also did not predict choosiness, desirability or successful dating matches, though it must be noted that these between-subject comparisons were underpowered.

In line with evolutionary models that implicate women as the 'choosier' sex [38], both choosiness and desirability scores were higher among women than men, with women showing a personal preference for only one-third of their dates (compared to one-half in men). Women also modulated more vocal parameters in response to preferred dating partners than did men, including their maximum pitch, and most notably, variability in their pitch, which is known to communicate masculinity and physical formidability among men [6]. This sex difference could be tied to ability or effort. Women have been shown to more effectively modulate their vocal attractiveness 'on demand' than men [14]. Alternatively, for women, dates marked as 'yes' were likely to include men whom women were maximally attracted to and may have thus exerted maximal vocal effort toward, whereas men's longer list of potential mates likely included marginally preferred partners toward whom men might have displayed less vocal effort.

Studying voice modulation in real-life dating offers high ecological validity, yet the lack of experimental manipulation does not allow for causal inferences regarding the role of various vocal parameters, or different modalities, on mate choice preferences. This may be investigated in future work using resynthesized speech as uni-modal and within multi-modal stimuli. Given our results, experiments are now also clearly needed to gauge the role of own versus group-level mate preferences on voice modulation. Our small sample size, while adequate for capturing dynamic within-individual modulation

across speed dates, limits the extent to which inferences can be made about between-individual differences in vocal parameters and behaviour. Individual difference factors, such as the influence of past dating experience, should thus be investigated in replication studies utilizing larger samples. Finally, future studies may examine the influence of stress (e.g., due to a first date or the realization of being audio-recorded) and other emotions on voice modulation in a dating context.

Although there is some recent evidence for behavioral and contextual flexibility in the vocalizations of other mammals and great apes [22], the capacity for volitional vocal control in humans is unprecedented in its complexity and thus, in its potential breadth of functionality. Indeed, this study shows that, while integral to human speech production, voice modulation also affects the nonverbal dimensions of vocal communication during mate choice. The capacity for women and men to dynamically alter their voice pitch therefore has the potential to affect reproductive success, but beyond this, may function to manipulate the perceptions and behaviours of others in a wide range of social, economic and political contexts [22].

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Authors' contributions

K.P. and D.R. designed the investigation. K.P., M.G. and A.O. collected the data. J.P prepared audio files and questionnaire data for analysis. K.P performed acoustic analysis. K.P., and D.R. performed statistical analyses. K.P. wrote the manuscript and

created the figures. The manuscript was reviewed, edited and approved by all authors, who agree to be accountable for the work.

Competing interests

The authors report no competing interests.

Ethics

The study was reviewed and approved by the Sciences and Technology Cross-Schools Research Ethics Committee (C-REC) of the University of Sussex (ER-REBY-3, ER-KP292-3/4).

Data availability

The dataset supporting this article will be uploaded to figshare.

FIGURE LEGEND

Figure 1. Women's and men's *F*0 modulation across speed dates. Panels (a) and (c) show main effects of personal mate choice preferences on voice pitch modulation, whereas panels (b) and (d) show interactions between personal preferences and date's overall desirability. Columns in bar graphs represent estimated marginal means from LMMs (see Tables 1 and S2), where error bars represent standard errors of the means. Markers in scatterplots represent individual speed dates; markers for distinct categories are minimally offset along the x-axis to avoid overplotting and to improve visualisation. Asterisks' indicate statistical significance of pairwise comparisons following Šidák correction, where *** p<.001, ** p<.01, *p<.05, and ^{ns} p>.05. Correlation coefficients (r) are given beside each linear regression line. See embedded legend for additional details.

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