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# Male Vocal Quality and Its Relation to Females' Preferences

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1 **Title: Male vocal quality and its relation to females' preferences**

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27 **Abstract**

28 In both correlational and experimental settings, studies on women’s vocal preferences have  
29 reported negative relationships between perceived attractiveness and men’s vocal pitch,  
30 emphasizing the idea of an adaptive preference. However, such consensus on vocal  
31 attractiveness has been mostly conducted with native English speakers, but a few evidence  
32 suggest that it may be culture-dependent. Moreover, other overlooked acoustic components of  
33 vocal quality, such as intonation, perceived breathiness and roughness may influence vocal  
34 attractiveness. In this context, the present study aims to contribute to the literature by  
35 investigating vocal attractiveness in an underrepresented language (i.e., French) as well as  
36 shedding light on its relationship with understudied acoustic components of vocal quality.  
37 More specifically, we investigated the relationships between attractiveness ratings as assessed  
38 by female raters and male voice pitch, its variation, the formants’ dispersion and position, and  
39 the harmonics-to-noise and jitter ratios. Results show that women were significantly more  
40 attracted to lower vocal pitch and higher intonation patterns. However, they did not show any  
41 directional preferences for all the other acoustic features. We discuss our results in light of the  
42 adaptive functions of vocal preferences in a mate choice context.

43 **Keywords**

44 Attractiveness; fundamental frequency; formants; intonation; breathiness; roughness; mate  
45 choice.

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## 52 **Introduction**

53 Voice is one of the fundamental aspects of human communication. Indeed, research has  
54 reported that acoustic signals provide listeners with information on the quality or condition of  
55 the speaker such as sex (Bachorowski and Owren, 1999; Gelfer and Bennett, 2013; Gelfer and  
56 Mikos, 2005; Hillenbrand and Clark, 2009), age (Linville and Fisher, 1985; Ptacek, and  
57 Sander, 1966; Shipp, Qi, Huntley, and Hollien, 1992), sexual orientation (Lyons, Lynch,  
58 Brewer, and Bruno, 2014; Munson, McDonald, DeBoe, and White, 2006), physical strength  
59 (Sell, Bryant, Cosmides, Tooby, Sznycer, von Rueden, Krauss and Gurven, 2010), sexual  
60 behavior and body configuration (Hughes, Dispenza, and Gallup, 2004). In this context,  
61 numerous studies have explored the relationships between acoustic features of speech and  
62 several auditory impressions, among which, attractiveness as assessed by opposite-sex  
63 members. Focus has especially been given to sexually dimorphic acoustic traits such as the  
64 fundamental frequency (i.e., F0, the acoustic correlate of voice pitch) and the formant  
65 frequencies (i.e., the resonances of the vocal tract, the acoustic correlate of perceived timbre)  
66 (Titze, 1989).

67 In both correlational and experimental settings, most studies have reported a consistent  
68 negative relationship between men's F0 and attractiveness, that is, women are attracted to  
69 relatively low-pitched voices (Bruckert, Lienard, Lacroix, Kreutzer, and Leboucher, 2006;  
70 Collins, 2000; Feinberg, Jones, Little, Burt, and Perrett, 2005; Hodges-Simeon, Gaulin, and  
71 Puts, 2010; Hughes, Farley, and Rhodes, 2010; Jones, Feinberg, DeBruine, Little, and  
72 Vukovic, 2010; Pisanski and Rendall, 2011; Vukovic, Feinberg, Jones, DeBruine, Welling,  
73 Little and Smith, 2008; Xu, Lee, Wu, Liu, and Birkholz, 2013). Relatively lower formants'  
74 dispersion (i.e., Df, the relative distance between two consecutive formants, which is  
75 correlated to the vocal tract length), were also found to be more attractive in male voices  
76 (Hodges-Simeon et al., 2010; Pisanski and Rendall, 2011). Although two studies have found

77 non-significant relationships (Babel, McGuire, and King, 2014; Feinberg et al., 2005), the  
78 former reported that larger females tended to prefer increased apparent vocal tract size (which  
79 positively correlates with a larger body size) while the latter reported that lower first  
80 formants' frequencies for the vowels /i/ and /u/ were judged as more attractive; still, both  
81 studies suggested that apparent vocal tract size influences vocal attractiveness. Additionally,  
82 although it has received little attention compared to the F0 and Df, one study has reported that  
83 lower F0-SD (i.e., the evolution of F0 through time, which acoustically correlates to micro  
84 variations of intonation patterns in continuous speech) was more attractive in men (Hodges-  
85 Simeon et al., 2010), although two other studies have reported the opposite relationship  
86 (Bruckert et al., 2006; Leongómez, Binter, Kubicová, Stolařová, Klapilová, Havlíček, and  
87 Roberts, 2014).

88 Under the scope of human sexual selection, three ultimate accounts can be invoked to  
89 explain the relationships between females' preferences and men's voices. Firstly, there is  
90 intersexual selection, which corresponds to the selection exerted by one sex over another. For  
91 instance, lower F0s were found to be positively associated to higher circulating testosterone  
92 levels in men (Dabbs and Mallinger, 1999; Evans, Neave, Wakelin, and Hamilton, 2008;  
93 Hodges-Simeon, Gurven, and Gaulin, 2015; Jost, Fuchs, Loeffler, Thiery, Kratzsch, Berger,  
94 and Engel, 2018; although see Arnocky, Hodges-Simeon, Ouellette, and Albert, 2018;  
95 Bruckert et al., 2006; Puts, Apicella, and Cardenas, 2012), which is known to act as an  
96 immunosuppressant (Foo, Nakagawa, Rhodes, and Simmons, 2017). As men possessing high  
97 testosterone levels should have a better immune system to bear its costs, lower F0s may thus  
98 signal health status as a result of possessing 'good genes' (Folstad and Karter, 1992). If so,  
99 females may then be attracted to such men as they represent higher genetic quality mates  
100 (Arnocky et al., 2018; Hodges-Simeon et al., 2015). Secondly, there is intrasexual selection,  
101 which corresponds to competition among same-sex individuals. For instance, it has been

102 regularly shown that lower F0s and Dfs were perceptually associated to larger, stronger, more  
103 masculine and more socially and physically dominant men (Hodges-Simeon et al., 2010;  
104 Pisanski, Fraccaro, Tigue, O'Connor, and Feinberg, 2014a; Puts, Gaulin, and Verdolini, 2006;  
105 Puts, Hodges, Cárdenas, and Gaulin, 2007; Rendall, Vokey, and Nemeth, 2007; Sell et al.,  
106 2010), with F0 being recently argued to signal formidability (Puts and Aung, 2019; although  
107 see Feinberg, Jones, and Armstrong, 2019). Additionally, lower F0-SD (i.e., monotonous  
108 voices) has been hypothesized to be a marker of self-confidence and experience and is also  
109 associated to perceived dominance in men (Hodges-Simeon et al., 2010). In this context, if  
110 women are attracted to more dominant and formidable men, then the formers might display a  
111 preference for lower F0s and Dfs. Lastly, a sensory bias may explain vocal attractiveness  
112 relationships. Humans possess a cognitive bias to associate deeper vocal frequencies to  
113 perceptually larger individuals (Pisanski and Rendall, 2011; Rendall, Vokey, and Nemeth,  
114 2007; Xu et al., 2013), although the relationships between vocal pitch and resonant  
115 frequencies with height and weight are relatively weak (Pisanski, Fraccaro, Tigue, O'Connor,  
116 Röder, Andrews, Fink, DeBruine, Jones, and Feinberg, 2014b). Nonetheless, if women  
117 actually prefer larger men as mates, then they might also prefer men with perceptually deeper  
118 vocal features.

119         According to the source-filter theory of speech production (Taylor and Reby, 2010),  
120 the underlying mechanisms of phonation in humans rests on the larynx (the source) and the  
121 subsequent filtering of vocal signals by the supralaryngeal vocal tract (the filter). The airflow  
122 expelled from the lungs and forced out through the glottis causes mechanical oscillations of  
123 the vocal folds within the larynx (i.e., Bernoulli's principle). The tension, length and thickness  
124 of vocal folds determine the vocal height, which acoustically correlates to the fundamental  
125 frequency (i.e., F0). Namely, the sound waves produced by the vocal folds' oscillations travel  
126 through the pharyngeal, the oral and (possibly) the nasal cavities before being expelled.

127 During this process, the vocal tract configuration filters the laryngeal flow generated at the  
128 glottis by amplifying some frequencies to the detriment of others and, thereby, producing the  
129 formant frequencies that lead to the perception of vocal timbre. Moreover, the movements of  
130 the articulatory organs involved in speech production such as the tongue, the lips and the  
131 palate modify the shape of the vocal tract, which determine the frequencies associated to the  
132 different speech sounds. In humans, both pitch and resonant frequencies display salient sex  
133 differences. Indeed, at puberty, males experience a significant influence of androgens,  
134 especially testosterone, which entails important consequences on larynx size and vocal folds  
135 thickness and length, which acoustically lower the voice pitch, deepen the resonant  
136 frequencies and reduce their spacing. This proximate mechanism explains why before  
137 puberty, boys and girls exhibit similar vocal frequencies (Fitch, 1999), until the former  
138 practically do not overlap with those of adults females (Titze, 1989). Additionally, in the adult  
139 life, inter-individual variations in vocal features are influenced by age (Linville and Fisher,  
140 1985; Shipp et al., 1992), circulating androgens level (Abitbol, Abitbol, and Abitbol, 1999;  
141 Akcam, Bolu, Merati, Durmus, Gerek, and Ozkaptan, 2004; Dabbs and Mallinger, 1999) and,  
142 possibly, to the exposure of testosterone in-utero (Fouquet, Pisanski, Mathevon, and Reby,  
143 2016).

144 Fundamental and formant frequencies aside, a few understudied vocal features also  
145 seem to contribute to vocal quality, such as vocal breathiness and vocal roughness. Firstly,  
146 vocal breathiness can be captured by the harmonics-to-noise ratio (HNR), which corresponds  
147 to a ratio between periodic components (i.e., the harmonics, which are multiple integer of the  
148 F0) and a non-periodic component (i.e., noise) comprising a segment of voiced speech  
149 (Teixeira, Oliveira, and Lopes, 2013). More specifically, this ratio reflects the efficiency of  
150 speech production. The greater the airflow expelled from the lungs into energy of vibration of  
151 the vocal folds, the higher the HNR, which is perceptually associated with a more sonorant

152 and harmonic voice. Conversely, a lower HNR is generally associated with a perceptually  
153 asthenic, dysphonic and breathier voice. Secondly, vocal roughness can be captured by the  
154 jitter, a measure of the F0 disturbance, which is defined as the parameter capturing the  
155 frequency variation at the glottis from cycle to cycle in the sound wave (Hillenbrand, 1988;  
156 Rabinov, Kreiman, Gerratt, and Bielałowicz, 1995; Wendahl, 1966). More specifically, the  
157 jitter measures the regularity of the vocal folds during successive periods of oscillations. The  
158 higher the jitter, the “rougher” sounds the voice. Although little is known about their  
159 physiological mechanisms, it has been suggested that both acoustic components may be  
160 sensitive to hormonal influx as they both relate to the oscillations of the vocal folds, which  
161 possess receptors to circulating androgens (Pisanski, Jones, Fink, O'Connor, DeBruine, Röder,  
162 and Feinberg, 2016).

163         Vocal breathiness has been suggested to be an important component of vocal  
164 attractiveness in female voices (Babel et al., 2014; Van Borsel, Janssens, and De Bodt, 2009),  
165 but significant relationships have been reported in both sexes (Šebesta, Kleisner, Tureček,  
166 Kočnar, Akoko, Třebický, and Havlíček, 2017; Xu et al., 2013). Thus, lower HNR profiles  
167 (i.e., breathy voices) have been suggested to be more attractive. Additionally, it has been  
168 suggested to soften the aggressiveness of males with larger body size (Xu et al., 2013), which  
169 in turn could increase their overall attractiveness towards females. On the other hand, little  
170 evidence is actually known on whether vocal roughness (as measured with the jitter)  
171 significantly contributes to perceived vocal attractiveness as studies that have directly tackled  
172 the topic have led to mixed results (Babel et al., 2014; Hughes, Mogilski, & Harrison, 2014;  
173 Hughes, Pastizzo, & Gallup, 2008).

174         Interestingly, experimental consensus regarding the F0 strongly suggests that women’s  
175 vocal preferences are consistent independently of the culture under study. Negative  
176 relationships have been mostly reported in English-speaking populations such as Americans



177 (Hodges-Simeon et al., 2010), Canadians (Feinberg et al., 2005; Pisanski and Rendall, 2011),  
178 British (Jones et al., 2010; Vukovic et al., 2008), Scottish (Saxton, Debruine, Jones, Little,  
179 and Roberts, 2009), and Australians (Simmons, Peters, and Rhodes, 2011), but also in Dutch  
180 (Collins, 2000), German (Weiss and Burkhardt, 2010), Czech (Valentová, Roberts, and  
181 Havlíček, 2013), Latvians (Skrinda, Krama, Keeko, Moore, Kaasik, Meija, Lietuviētis,  
182 Rantala, and Krams, 2014) and in a small sample of French speakers (Bruckert et al., 2006).  
183 Although evidence is scarce, a few findings challenges this view, suggesting that vocal  
184 attractiveness may rest on different acoustic cues depending on the culture under study. For  
185 instance, one study reported that in a Filipino-speaking group sample, both nulliparous and  
186 breastfeeding women showed a preference for feminized (i.e., higher F0) rather than  
187 masculinized voice pitch (i.e., lower F0) (Shirazi, Puts, and Escasa-Dorne, 2018). In the  
188 Hadzas, it has also been reported that women who are breastfeeding prefer men with higher  
189 pitch voices as mates, those who are not breastfeeding preferring lower pitch male voices  
190 (Apicella and Feinberg, 2009). Interestingly, another study found that Namibian men's vocal  
191 attractiveness could be predicted by their degree of vocal breathiness (measured through the  
192 HNR) and not by their voice pitch (Šebesta et al., 2017).

193 In this context, the aim of this replication study is to investigate culture-dependency  
194 for vocal attractiveness in an underrepresented language (i.e., French) as well as investigating  
195 attractiveness relationships with understudied acoustic features of vocal quality.

## 196 **Material and Methods**

197 This study was conducted in Montpellier, France. The French National Commission of  
198 Informatics and Liberty approved the experimental designs of the present study (CNIL  
199 number 2-17029). Prior to the study, all participants provided the investigator with their  
200 written consent.

### 201 **a. Stimuli**

202 An aggregate of 58 male participants (mean age = 23; SD = 3.36), native speakers of French,  
203 produced the vocal stimuli. These participants were drawn from another study (Suire,  
204 Raymond, and Barkat-Defradas, 2018; two of which were not included in that study). They  
205 were seated in a quiet, anechoic, soundproof room equipped with a Sennheiser™ BF 515  
206 microphone connected to a PC located in another room. Vocal samples consisted in the  
207 recording of a short utterance ‘*Dans la vie, je pense toujours prendre les bonnes decisions et*  
208 *c’est pour cela que je vais gagner*’ (i.e., ‘In life, I always think I’ll make the right decision  
209 and that is why I will win’). To control for intensity, participants were asked to speak at a  
210 constant distance of 15 cm from the microphone. All recordings were encoded using the  
211 Adobe© Audition CS6 at a sampling rate of 44 kHz – 32 bit – mono then saved as .wav files.

#### 212 **b. Acoustic analyses**

213 All recordings were analyzed using the Praat© voice analysis software (version 6.0.31,  
214 Boersma and Weenink, 2018). The mean fundamental frequency (F0) and its variation (F0-  
215 SD) were measured using the autocorrelation method with a pitch floor of 75 Hz and a ceiling  
216 of 300 Hz (Praat’s recommendation), with other settings kept as default. The harmonics-to-  
217 noise ratio (HNR, in dB) and the local jitter (%), which corresponds to the average absolute  
218 difference between consecutive periods, divided by the average period, and calculated in  
219 percentage, were measured across the entire utterance using the same settings as the F0. The  
220 local jitter corresponds to the jitter ratio, which is commonly used to describe vocal  
221 perturbations (Jones, Trabold, Plante, Cheetham, and Earis, 2001). Additionally, intensity  
222 (dB) was retrieved using Praat’s default settings. Formant frequencies (F1 to F4) were  
223 measured at each glottal pulse, targeting voiced speech only, using a formant ceiling of 5000  
224 Hz (Praat’s recommendation), then averaged across the entire utterance. Then, the formants’  
225 dispersion (Df) was calculated using the following formula (Fitch, 1997):

$$Df = \frac{\sum_{i=1}^{N-1} F_{i+1} - F_i}{N - 1},$$

226 where Df is the formant dispersion (in Hz),  $N$  is the total number of formants measured, and  
 227  $F_i$  is the frequency (in Hz) of formant  $i$ . Lastly, we computed the formants' position (Pf)  
 228 using the method described in Puts et al. (2012), which has been argued to be sexually more  
 229 dimorphic than Df. To compute the formants' position, we used female vocal stimuli that  
 230 were drawn from the same study of the male vocal stimuli ( $n_{\text{female}} = 68$ , Suire et al. 2018).

231 Descriptive statistics of the male vocal stimuli for each acoustic feature are reported in  
 232 Table 1 and their zero-order correlations in Table 2. Mean F0 was positively correlated with  
 233 F0-SD ( $r = 0.56$ ,  $p < 0.001$ ). Df was positively associated to Pf ( $r = 0.31$ ,  $p = 0.019$ ) and HNR  
 234 ( $r = 0.35$ ,  $p = 0.008$ ). Lastly, HNR was negatively correlated with jitter ( $r = -0.57$ ,  $p < 0.001$ ).  
 235 All these correlations are consistent with those reported in the literature (for F0 and F0-SD,  
 236 see Hodges-Simeon et al., 2010; for Df and Pf see the open data of Han, Wang, Fasolt, Hahn,  
 237 Holzleitner, Lao, DeBruine, Feinberg and Jones, 2018; for jitter and HNR, see de Krom,  
 238 1993), except the correlation between Df and HNR, which to our knowledge was not reported  
 239 elsewhere.

n = 58	Mean	SD	Ranges
Mean F0 (Hz)	114.47	11.84	85.44 – 140.07
F0-SD (Hz)	15.16	5.06	6.97 – 28.31
Df (Hz)	1086.78	36.60	1005 – 1181
Pf (Hz)	-1.61	0.47	-2.47 – -0.65
HNR (dB)	11.32	1.37	7.93 – 14.94
Jitter (%)	2.68	0.47	1.83 – 4.41
Intensity (dB)	64.73	3.61	53.96 – 76.93

240 Table 1. Descriptive statistics of the acoustic characteristics of the vocal stimuli.

	Mean F0 (Hz)	F0-SD (Hz)	Df (Hz)	Pf (Hz)	HNR (dB)	Jitter (%)	Intensity (dB)
Mean F0 (Hz)	1						
F0-SD (Hz)	0.56***	1					
Df (Hz)	-0.16	-0.13	1				
Pf (Hz)	0.16	0.10	0.31*	1			
HNR (dB)	0.13	-0.24	0.35**	-0.06	1		
Jitter (%)	-0.15	0.20	0.13	-0.14	-0.57***	1	

Intensity (dB)	0.13	0.02	0.24	0.05	0.22	-0.08	1
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242 Table 2. Zero-order correlations between each acoustic feature for the vocal stimuli.

243 Significance code: \*\*\*  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ .

### 244 c. Experimental procedure

245 The experimental procedure was automated on an online computer-interfaced program. 224  
 246 French female raters participated in a perceptual study after they self-reported in a  
 247 questionnaire their age, origins of parents and grandparents (to control for potential cultural  
 248 preferences), sexual orientation (to control for sexual preferences) and whether they suffered  
 249 from a hearing impairment (note that other information were reported but are not used in the  
 250 present study). After filling out the questionnaire, female raters were presented with a series  
 251 of 11 choices each including a pair of voices. For each pair, two stimuli were randomly  
 252 selected from the whole pool of vocal stimuli. The two vocal stimuli were randomized in their  
 253 position presented in each pair (left or right position) on the computer screen. Judges were  
 254 asked to choose the most attractive vocal stimulus by clicking on it. Participants were allowed  
 255 to listen to the stimuli as much as they wanted. However, when the female judge made her  
 256 choice, she could not go back to the previous one anymore. To measure intra-rater reliability,  
 257 the second and third pairs were the same as the tenth and eleventh pairs.

258 Although a forced choice paradigm is usually implemented with experimentally  
 259 manipulated vocal stimuli (e.g. Jones et al., 2010; Re, O'Connor, Bennett, and Feinberg,  
 260 2012), there is fundamentally no advantage or disadvantage between a forced-choice  
 261 paradigm and a correlational rating study for either manipulated or non-manipulated stimuli.  
 262 Crucially, it does not yield different results (e.g. for women's preferences of men's F0, for  
 263 experimental designs see: Vukovic et al. 2008; Jones et al. 2010; Re et al. 2012; and for  
 264 correlational designs see: Feinberg et al. 2005; Hodges-Simeon et al. 2010; Pisanski and  
 265 Rendall 2011).

266 We stopped collecting data when each voice of the 58 voices was heard at least 40

267 times in order to obtain statistically relevant data. In the end, the mean number of times a  
 268 voice has been heard is  $M \pm SD = 54.14 \pm 6.55$ , with 72 and 42 times respectively for the  
 269 most and least heard voices.

270 Out of the 225 female participants who completed the questionnaire, 137 participants  
 271 completed all 11 decisions, 28 participants skipped some of the decisions (mean number of  
 272 skipped decisions = 8.75), for a total of 1570 decisions in our analyses. Description of the  
 273 judges' characteristics that completed at least one pair ( $n = 165$ ,  $M \pm SD = 28.95 \pm 14.16$ ) are  
 274 given in Table 3.

		n
Completed the full test		
	<i>No</i>	28
	<i>Yes</i>	137
Ancestry		
	<i>European</i>	135
	<i>Non-European</i>	30
Sexual orientation		
	<i>Heterosexual</i>	142
	<i>Homosexual</i>	4
	<i>Bisexual</i>	11
	<i>Not reported</i>	8
Hearing impairment		
	<i>No</i>	161
	<i>Yes</i>	3
	<i>Not reported</i>	1

275 Table 3. Number of judges for each of the following categories: those who completed the full  
 276 test (i.e., heard all the pairs), grandparents' ancestry, sexual orientation and hearing  
 277 impairments.

#### 278 **d. Data analysis**

279 To analyze women's preferences for men's voices, a generalized linear mixed model  
 280 (GLMM) was used with the response variable being if the female judge chose or not the voice  
 281 presented to her on the left position. The GLMM was fitted with a binomial error structure  
 282 since the response variable consisted in a discrete probability distribution of the number of

283 successes in a sequence of several independent trials. In order to explore acoustics'  
284 preferences, seven predictor variables were computed and corresponded to the differences  
285 observed in mean F0, F0-SD, Df, Pf, HNR, jitter and intensity between the two vocal stimuli  
286 (numerical variables that were standardized). Judges' age (standardized variable), ancestry  
287 (i.e., European or non-European grandparents') and sexual orientation (i.e., heterosexual and  
288 non-heterosexual) were added as control variables and put in interaction with the differences  
289 in acoustics characteristics to assess their influence on voice preferences. Judges' identities  
290 and the vocal stimuli were added as random effects as intercepts only. A symbolic  
291 representation of the GLMM is given in the supplementary material.

292 GLMMs with and without the control variables were performed to explore any  
293 statistical differences. Moreover, we performed two additional GLMMs, one without  
294 individuals with hearing impairment and one without individuals who did not report sexual  
295 orientation (these individuals were treated as non-heterosexual in the main GLMM). The  
296 significance of each predictor in all GLMMs was assessed from the comparison of the model  
297 excluding the predictor with the model including all the other predictors (i.e., likelihood-ratio  
298 chi-square tests, ANOVA type III). Additionally, since some acoustic variables are highly  
299 correlated (see Table 2), we conducted multicollinearity checks on the GLMMs using the  
300 variation inflation factors (VIFs).

301 All statistical analyses were performed under the R software (version 3.4.0), using the  
302 following packages: 'lme4' to build the generalized linear models with random effects (Bates,  
303 Mächler, Bolker, and Walker, 2014), 'car' to compute the statistical significance of each  
304 predictor and check potential multicollinearity problems for the GLMMs (Fox, Weisberg, and  
305 Fox, 2011) and 'MuMIn' to compute the pseudo- $R^2$  (Bartoń, 2018). In order to illustrate the  
306 results with figures, we used 'boot' to transform the coefficients of the GLMMs back into  
307 probabilities (Canty and Ripley, 2012), 'dplyr' to compute the predictions of the model

308 (Wickham, François, Henry, and Müller, 2018) and ‘ggplot2’ for the resulting figures  
 309 (Wickham, 2009).

## 310 Results

311 Descriptive statistics of the mean difference in acoustic features are reported in Table 4.

	Mean	SD	Ranges
Difference in mean F0	-0.38	16.70	-53.28 – 49.84
Difference in F0-SD	-0.066	6.89	-20.79 – 20.43
Difference in Df	1.25	51.73	-176.66 – 176.66
Difference in Pf	0.003	0.66	-1.81 – 1.81
Difference in HNR	-0.0086	1.91	-5.73 – 5.58
Difference in jitter	0.013	0.64	-2.58 – 2.58
Difference in intensity	0.065	5.06	-20.63 – 22.97

312 Table 4. Descriptive statistics for the unstandardized mean difference for each acoustic feature  
 313 summarized over the total number of observations (n = 1570).

314 We computed intra-rater reliability scores by calculating the proportion of identical  
 315 chosen vocal stimuli between the second and third first pairs with the tenth and eleventh pairs.  
 316 Intra-rater reliability was high:  $M \pm SD = 0.791 \pm 0.257$ , i.e., judges considered on average  
 317 more than 2/3 the same voices as attractive.

318 Results of the main GLMM are reported in Table 5. VIFs were all inferior to 4,  
 319 indicating no problems of multicollinearity. When presented with two voices, women  
 320 preferred lower F0 ( $\chi^2_1 = 24.89$ ,  $p < 0.001$ ), higher F0-SD profiles ( $\chi^2_1 = 34.00$ ,  $p < 0.001$ ) and  
 321 louder stimuli ( $\chi^2_1 = 7.52$ ,  $p = 0.006$ ).

	Estimate	SE	$\chi^2$	<i>p value</i>
Intercept	0.09	0.06	/	/
Difference in mean F0	-0.49	0.10	24.89	<b>&lt;0.001</b>
Difference in F0-SD	0.53	0.09	34.00	<b>&lt;0.001</b>
Difference in Df	0.18	0.10	3.26	0.070
Difference in Pf	-0.06	0.08	0.56	0.452
Difference in HNR	-0.12	0.10	1.23	0.266
Difference in jitter	-0.04	0.09	0.27	0.602
Difference in intensity	0.18	0.06	7.52	<b>0.006</b>
<b><u>Interactions with age</u></b>				
Difference in F0	0.16	0.09	2.86	0.090

Difference in F0-SD	0.04	0.09	0.25	0.616
Difference in Df	0.13	0.09	2.06	0.151
Difference in Pf	-0.06	0.07	0.70	0.399
Difference in HNR	-0.11	0.09	1.31	0.251
Difference in jitter	0.10	0.08	1.61	0.204
Difference in intensity	0.15	0.06	5.65	<b>0.017</b>
<b><u>Interactions with ancestry</u></b>				
Difference in F0	-0.008	0.22	0.001	0.968
Difference in F0-SD	-0.41	0.20	3.97	<b>0.046</b>
Difference in Df	0.04	0.23	0.03	0.863
Difference in Pf	-0.17	0.18	0.82	0.364
Difference in HNR	-0.01	0.25	0.003	0.953
Difference in jitter	0.06	0.21	0.09	0.752
Difference in intensity	-0.10	0.17	0.37	0.539
<b><u>Interactions with sexual orientation</u></b>				
Difference in F0	0.15	0.24	0.38	0.534
Difference in F0-SD	-0.54	0.23	5.49	<b>0.019</b>
Difference in Df	-0.14	0.23	0.36	0.544
Difference in Pf	-0.10	0.18	0.28	0.593
Difference in HNR	-0.11	0.28	0.15	0.691
Difference in jitter	0.18	0.24	0.60	0.436
Difference in intensity	0.27	0.18	2.29	0.130

322 **Table 5.** Results of the GLMM predicting women’s preferences for men’s voices, ( $n_{\text{stimuli}} =$   
323  $58$ ,  $n_{\text{judges}} = 165$ ,  $n_{\text{observations}} = 1570$ ). For each variable, the  $\chi^2$  and the p values associated from  
324 the likelihood-ratio chi-square test of the comparison between the full model and the model  
325 without the predictors and the control variables are given (ANOVA type III). For the  
326 categorical variables’ ‘ancestry’ and ‘sexual orientation’, the estimates are given compared to  
327 the reference category (1 = European ancestry and 1 = heterosexual). P values are considered  
328 significant at the 0.05 threshold (in bold). The degrees of freedom is 1 for every test.

329 For easier understanding of the model’s output, the predicted probabilities of  
330 considering a voice more attractive than the other within the same pair were plotted against  
331 the range of differences in mean F0, F0-SD and intensity between the two voices (Figure 1).  
332 Figure 1. Probabilities of being picked as more attractive plotted against the standardized  
333 differences between the two voices heard in a) mean F0, b) F0-SD and c) intensity. The black  
334 curves represent the model’s predictions associated with 95% confidence intervals (in grey).

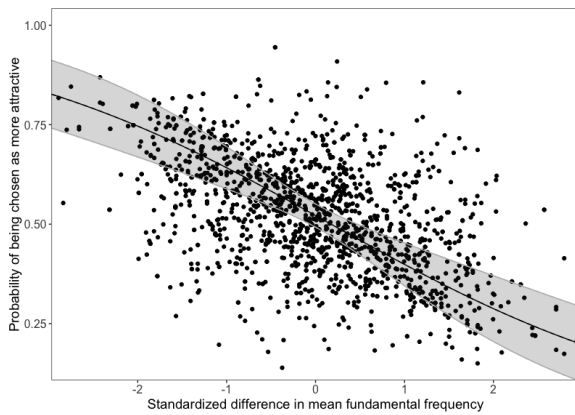
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336

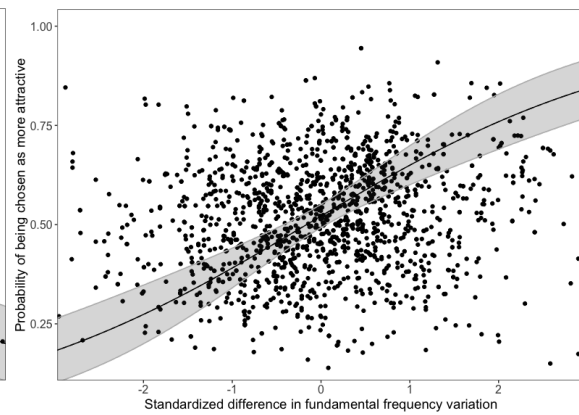


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a)



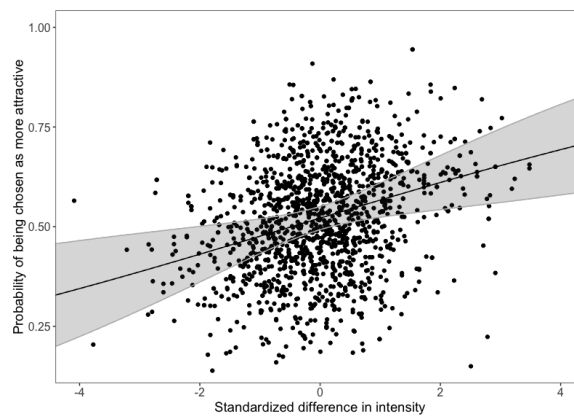
b)



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c)



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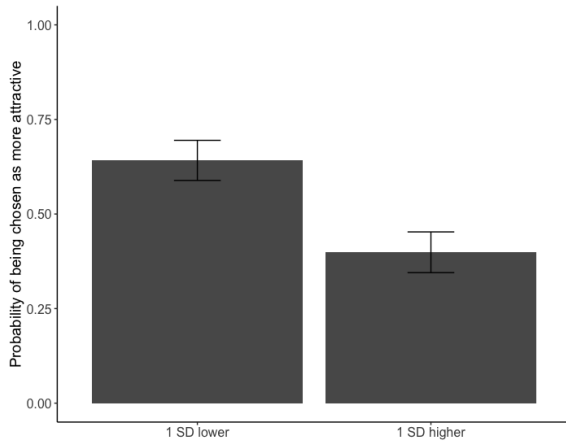
351

We also computed the predicted probability that a voice would be considered more attractive when it is 1 standard deviation lower and 1 standard deviation higher than the opposite one on the basis of their F0, F0-SD and intensity (Figure 2). A voice with a mean F0 that is one standard deviation lower than the other in the same pair has a probability of being picked as more attractive up to ~65%, likewise, a voice with a F0-SD which is 1 standard deviation higher has a probability of being picked as more attractive up to ~65%.

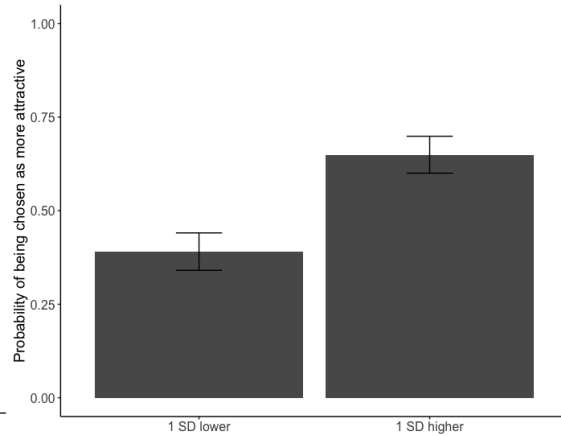
Figure 2. Barplots of the predicted probabilities that a voice would be considered more attractive when it is 1 standard deviation lower and 1 standard deviation higher than the other voice, as a function of its a) mean F0, b) F0-SD and c) intensity. Bars are associated with 95% confidence intervals.

352

a)



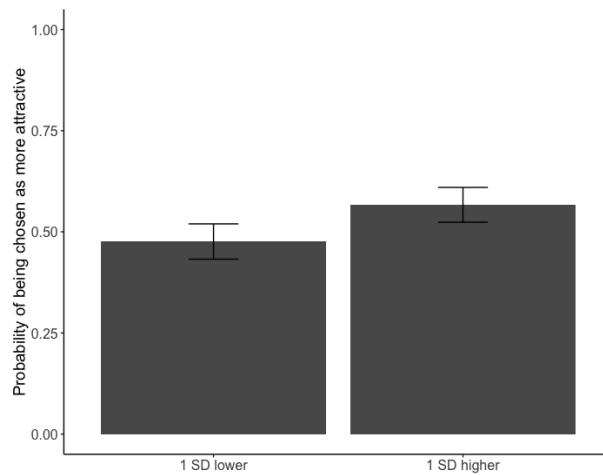
b)



353

354

c)



355

356 Additionally, female judges did not show directional preferences for Df, Pf, HNR or

357 jitter (all p values > 0.05). Judges' age had a significant influence on their preferences for

358 intensity ( $\chi_1^2 = 7.52$ ,  $p = 0.006$ ), i.e., relatively older women preferred louder vocal profiles.

359 Women with non-European ancestry and non-heterosexual women showed a preference for

360 lower F0-SD profiles (respectively  $\chi_1^2 = 3.97$ ,  $p = 0.046$ ;  $\chi_1^2 = 5.49$ ,  $p = 0.019$ ). The model

361 explained 12% of the variance in vocal preferences, including fixed and random effects.

362 Lastly, the variance of the random intercept for judges was higher than the vocal stimuli

363 ( $\sigma_{\text{judges}} = 0.07$ ;  $\sigma_{\text{stimuli}} = 0.01$ ).

364

The model without ancestry and the one without sexual orientation were not

365 statistically different from the full model (respectively  $\chi^2_7 = 10.42$ ,  $p = 0.165$ ;  $\chi^2_7 = 9.96$ ,  $p =$   
366  $0.190$ ). Removing age from the model was statistically different from the full model ( $\chi^2_7 =$   
367  $18.74$ ,  $p = 0.009$ ). The models without judges with hearing impairment and without judges  
368 who did not report sexual orientation did not qualitatively change the results. In all models,  
369 the main results remained the same: female judges still considered voices with lower F0,  
370 higher F0-SD and higher intensity as more attractive. All models without the control variables  
371 are given in the supplementary material.

## 372 **Discussion**

373 Women significantly preferred lower vocal pitch in men. This result is consistent with  
374 previous findings in English-speaking populations (Feinberg et al., 2005; Hodges-Simeon et  
375 al., 2010; Hughes et al., 2010; Jones et al., 2010; Pisanski and Rendall, 2011; Vukovic et al.,  
376 2008) and several other languages (Bruckert et al., 2006; Skrinda et al., 2014; Valentová et  
377 al., 2013; Weiss and Burkhardt, 2010). Moreover, this finding has been replicated with a  
378 similar or higher number of stimuli and judges than most of these studies (see Hodges-Simeon  
379 et al., 2010 for an example of a study with a higher number of stimuli). As vocal height  
380 correlates to several biological and social information about men, such as testosterone levels  
381 (Dabbs and Mallinger, 1999; Evans et al., 2008; Hodges-Simeon et al., 2015), sexually related  
382 behaviors (Hughes et al., 2004), body size assessments (Pisanski et al., 2014a), as well as  
383 signaling social dominance (Puts et al., 2007) and social rankings (Cheng, Tracy, Ho, and  
384 Henrich, 2016), women may rely on this salient acoustic cue as an assessment of sexual  
385 partner quality. Several studies have reported that men exhibiting relatively low-pitched  
386 voices reported a higher mating success in industrialized societies (Hodges-Simeon, Gaulin,  
387 and Puts, 2011; Puts, 2005; Puts et al., 2006; although see Suire et al., 2018) and a higher  
388 reproductive success in a hunter-gatherer society (Apicella, Feinberg, and Marlowe, 2007;  
389 although see Smith, Olkhov, Puts, and Apicella, 2017).

390           Moreover, French women also significantly preferred higher F0-SD profiles in men,  
391 that is, more expressive (or less monotonous) voices. Although our study had a higher number  
392 of judges and stimuli than the two others that reported the same relationship (Bruckert et al.,  
393 2006; Leongómez et al., 2014), another study had a higher number of stimuli but less judges  
394 (Hodges-Simeon et al., 2010). Nonetheless, while self-confidence and experience can be  
395 expressed through monotonous voices, to which some women may be more attracted to  
396 (Hodges-Simeon et al., 2010), our results do not follow the same tendency. A possible  
397 explanation may be that more marked intonation patterns might be perceived as more  
398 attractive as it is a marker of perceived state-dependent qualities such as positive emotions  
399 (e.g. joy and happiness) (Banse and Scherer, 1996), conversational interest as well as  
400 emotional activation (i.e., arousal) and intensity (Laukka, Juslin, and Bresin, 2005).  
401 Ultimately, expressive voices could reflect the speaker's current mental-health state since it  
402 has been previously reported that clinically depressed patients show typically reduced F0-SD  
403 values (Ellgring and Scherer, 1996). Thus, higher F0 variability may be associated to more  
404 enthusiastic and extroverted individuals, to which women may be more attracted. In this  
405 sense, our result is consistent with previous findings in both men and women (Bruckert et al.,  
406 2006; Leongómez et al., 2014). Although it has been suggested to be a cue of femininity, as  
407 women display twice as much F0 variation, we suggest that irrespective of sex, higher F0-SD  
408 profiles should be perceived as more attractive.

409           No directional preferences were observed for the formants' dispersion and position,  
410 which corroborates some previous findings (Babel et al., 2014; Feinberg et al., 2005), using a  
411 higher or similar number of stimuli and a higher number of judges. Several studies have  
412 suggested that Df may be a more important vocal cue to assess in human competitive settings.  
413 Indeed, it has been reported that lower Df patterns were associated to perceived dominance in  
414 men (Puts et al., 2007; Wolff and Puts, 2010). This can be explained by the fact that lower Df

415 patterns are associated to larger body size (Pisanski et al., 2016) and to perceived larger  
416 individuals (Bruckert et al., 2006; Collins, 2000; Rendall et al., 2007). Interestingly, females  
417 were also found to be more sensitive to this vocal cue than men after hearing women's voices  
418 (Puts, Barndt, Welling, Dawood, and Burriss, 2011). Such results emphasize the idea that  
419 same-sex individuals may use Df to track competitor's masculinity and/or femininity.  
420 Similarly, some research suggest that the formants' position may signal threat potential  
421 among men (Puts et al., 2012), although a recent study found no correlations to physical  
422 strength (Han et al., 2018).

423         Our results also indicated that vocal breathiness and roughness (assessed respectively  
424 through the HNR and the jitter ratio) did not significantly contribute to men's vocal  
425 attractiveness, using a higher number of stimuli and judges than previous studies (Babel et al.,  
426 2014; Hughes et al., 2014, 2008). Although one study reported that breathier voices were  
427 found to be more attractive in Namibian men, ours did not (Šebesta et al., 2017). Another  
428 study found that perceived 'breathy' voices were significantly more attractive in both sexes  
429 (Xu et al., 2013), although the underlying acoustic component was not clearly identified in  
430 this study. Lack of significant findings for breathiness suggests that it is more associated with  
431 feminine vocal quality, as previously suggested (Henton and Bladon, 1985; Van Borsel et al.,  
432 2009). It is also possible that when assessing attractiveness, women may be particularly  
433 attuned to the vocal features that are indicative of one's heritable mate quality, such as the F0.  
434 In this context, breathiness and roughness may not reliably indicate mate or competitor  
435 quality for listeners, at least in men. Although they are correlated to other body features (see  
436 Pisanski et al., 2016 for an extensive study on that matter), further studies are needed to  
437 understand whether these two acoustic components of the human voice are perceptually  
438 salient in influencing vocal attractiveness. Otherwise, it has been suggested that HNR and  
439 jitter may be indicative of current hormonal profiles as both parameters relate to the

440 oscillations of the vocal folds, which possess many cellular receptors to androgens (Pisanski  
441 et al., 2016).

442         An important limitation to the current study is that we did not investigate the effects of  
443 women's menstrual cycle upon perceived vocal attractiveness. Indeed, there was more  
444 variations between females judges than between vocal stimuli ( $\sigma_{\text{judges}} = 0.07$ ;  $\sigma_{\text{stimuli}} = 0.01$ ),  
445 suggesting, for example, that the timing of the ovulatory cycle may play a role. In fact, it has  
446 been long suggested that menstrual phase and mating contexts may influence women's  
447 preferences for masculine vocal attributes (Feinberg et al., 2006; Pisanski, Hahn, Fisher,  
448 DeBruine, Feinberg, and Jones, 2014c; Puts, 2005). Under the 'good genes ovulatory shift  
449 hypothesis', women in their fertile phase are predicted to shift their preferences towards mates  
450 indicating high genetic quality (i.e., more masculine men, to which women may be  
451 particularly attracted to for a short-term relationship, such as a one-night stand), as opposed to  
452 mates indicating high parental investment in their non-fertile phase (i.e., less masculine men,  
453 to which women may be particularly attracted to for a long-term, committed and romantic  
454 relationship) (Jünger, Kordsmeyer, Gerlach, and Penke, 2018). These shifting preferences  
455 have been suggested to be an adaptive strategy in order to maximize fitness benefits for  
456 women.

457         For instance, Puts (2005) found that females judged lowered pitch voices more  
458 attractive than the same voices raised in pitch in their fertile phase of their ovulatory cycle  
459 with respect to a short-term context. Similarly, Feinberg et al. (2006) found that women's  
460 masculinity preferences for low-pitched voices were stronger during the fertile phase.  
461 Although the effect was not significant, Pisanski et al. (2014c) also reported stronger  
462 preferences for masculinized voice pitch. Lastly, one study has reported that women in their  
463 fertile phase significantly preferred lowered Df when questioned for both short- and long-term  
464 relationships (Hodges-Simeon et al., 2010). The authors also found that mean F0 and

465 attractiveness was strongest for fertile-phase women rating short-term attractiveness, while  
466 F0-SD was more attractive for non-fertile phase female rating short-term attractiveness and  
467 fertile females rating long-term attractiveness. However, recent evidence have suggested that  
468 women menstrual cycle does not influence their preferences for masculinized bodies and  
469 faces (Jones, Hahn, Fisher, Wang, Kandrik, Han, Fasolt, Morrison, Holzleitner, O'Shea,  
470 Roberts, Little, and DeBruine, 2017; Marcinkowska, Galbarczyk, and Jasienska, 2018). Using  
471 a large sample size and a more methodologically grounded procedure, Jünger et al. (2018)  
472 found no effect of the cycle phase, conception risk and steroid hormone levels on women's  
473 auditory preferences for men's voices. Further research is thus needed to reliably investigate  
474 if the menstrual cycle has a significant effect over shifted preferences. In any case, not  
475 controlling for this factor will only provide conservative results, under the hypothesis that the  
476 time of the menstrual cycle is randomly distributed among the participating women.

477 Other limitations include the difference in age between men who provided the vocal  
478 stimuli and the female judges. However, in our sample both the youngest individual who  
479 provided the vocal stimuli and the youngest female judge were aged 18, which is largely  
480 above the age where mate preferences develop and become relevant (age 13-15, Saxton,  
481 Caryl, and Craig Roberts, 2006; Saxton, DeBruine, Jones, Little and Roberts, 2009).  
482 Moreover, an interesting perspective for future research would be to investigate possible non-  
483 linear effects of preferences as a function of vocal parameters. Indeed, extreme values for a  
484 particular vocal parameter may be perceived as pathological (as it is the case for high values  
485 of jitter and low values of HNR, Teixeira et al., 2013) or perceived as immature and/or too  
486 feminine (e.g. high F0). To our knowledge, only one study has tackled this topic in women's  
487 preferences for men's F0, and it was found that women did not prefer vocal pitches below the  
488 ~96 Hz threshold. This suggests that preferences may contribute to stabilizing selection  
489 pressure for low pitch in men's voices (Re et al., 2012 IL Y AUSSI LETUDE DE SAXTON).

490 Interestingly, in men's preferences for the F0 of women, one study reported a non-linear  
491 relationship with attractiveness ratings starting to decrease when the F0 is higher than ~260  
492 Hz (Borkowski and Pawlowski 2011), although two studies have reported that there was no  
493 upper limit (Feinberg, DeBruine, Jones, and Perrett, 2008; Re et al., 2012).

#### 494 **Conclusions**

495 The current study adds to the body of literature on vocal attractiveness in an  
496 underrepresented language (i.e., French). Although voice pitch findings were replicated,  
497 confirming women's preferences for low-pitched masculine voices, most of the other acoustic  
498 features investigated in this study did not yield to significant results, leading us to conclude  
499 that variations in resonant frequencies' spacing, breathiness and roughness do not seem to be  
500 important contributors of men's vocal attractiveness, at least in a French-speaking sample.  
501 Further studies should explore these relationships in other cultures so as to reaffirm these  
502 findings.

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#### 506 **Declaration of conflicting interests**

507 The authors declare that there is no conflict of interest.

#### 508 **Data availability**

509 The data and the R code from this study can be found at:

510 <https://figshare.com/s/cab62d1e411503982c91>

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