**No evidence for an association between facial fluctuating asymmetry and vocal
attractiveness in men and women**

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Abstract

Facial fluctuating asymmetry (FA), presumably a proxy measure of developmental instability, has been proposed to inversely relate to vocal attractiveness, which may convey information on heritable fitness benefits. Using an improved method of measuring facial FA, we sought to replicate two recent studies that showed an inverse correlation of facial FA with vocal attractiveness. In two samples of men ($N = 165$) and women ($N = 157$), we investigated the association between automatically measured facial FA based on 3D face scans and male and female observer-rated attractiveness of voice recordings. No significant associations were found for men or women, also when controlling for facial attractiveness, age and BMI. Equivalence tests show that effect sizes were significantly smaller than previous meta-analytic effects, providing robust evidence against a link of facial FA with vocal attractiveness. Thus, our study contradicts earlier findings that vocal attractiveness may signal genetic quality in humans via an association with FA.

Keywords: facial fluctuating asymmetry, developmental instability, vocal attractiveness, 3D face scans, geometric morphometrics

Introduction

Sexual selection is a type of natural selection that favours traits which aid in competition over mates. The two underlying main mechanisms are intersexual attraction of and intrasexual competition for mates (Puts, 2016). The former is based on a preference for opposite-sex individuals providing fitness benefits, including indirect, heritable fitness benefits (Gangestad & Thornhill, 1997; Gangestad, Thornhill, & Garver-Apgar, 2005). Heritable fitness benefits partly reflect an organism's capacity to buffer against interferences caused by developmental noise (Palmer & Strobeck, 2003). Random variations in developmental factors during ontogeny, detrimental mutations, or external stressors such as diseases, parasites and an inadequate diet impair ideal developmental conditions to some extent (Graham & Özener, 2016; Palmer & Strobeck, 2003). The inability to buffer against these perturbations is referred to as developmental instability (DI), which is assumed to indirectly signal low genetic quality (Van Dongen & Gangestad, 2011). Since the same genes equally influence development of both sides of the body (Gangestad & Thornhill, 1997; Van Valen, 1962), bilateral features should be expected to show perfect symmetry. However, DI is thought to morphologically manifest in interindividual differences in fluctuating asymmetry (FA). FA appears in bilateral morphological traits for which the differences between left and right sides of the body has a normal distribution with a population mean of zero (Van Valen, 1962). FA is thus considered an indicator of DI, with higher DI resulting in higher FA. In previous studies, FA has been shown to be related to different kinds of outcomes that can be considered as indicators of poor health in both nonhuman (e.g. probability of survival in the striped dolphin, Pertoldi et al., 2000; ejaculate quality in gazelles, Roldan, Cassinello, Abaigar, & Gomendio, 1998) and human animals (maternal risk factors, Singh & Rosen, 2001; schizophrenia, Yeo, Gangestad, Edgar, & Thoma, 1999; for a meta-analysis, see Van Dongen & Gangestad, 2011). Concerning heritable

fitness benefits, low FA was found to be related to greater mating success in men. For example, men's ($N = 203$) number of self-reported extra-pair copulation (EPC) partners (Gangestad & Thornhill, 1997) and lifetime sexual partners ($N = 60$, Thornhill & Gangestad, 1994) were negatively correlated with their bodily FA scores (but see Kordsmeyer & Penke, 2017 for null-replications of these findings, $N = 284$).

Since FA is assumed to be an indicator of genetic quality via its link with DI, it may also relate to an individual's physical attractiveness. Several studies have shown inverse correlations between FA and visual perceptions of physical attractiveness in humans (bodily FA: Brown et al., 2008, $N = 77$ target participants, $N = 87$ raters; facial FA: Grammer & Thornhill, 1994, $N = 32$ target participants, $N = 96$ raters; Komori, Kawamura, & Ishihara, 2009, $N = 96$ target participants, $N = 114$ raters; Simmons, Rhodes, Peters, & Koehler, 2004, $N = 377$ target participants, $N = 111$ raters). Since DI is not perceptible due to it merely being an underlying mechanism of attractiveness, drawing conclusions about the relationship between the two is problematic. The relationship between FA and DI can be confounded by directional asymmetry (DA), which is assumed to be uninformative of DI and appears in traits where the left-right difference across a population has a normal distribution with a mean deviating from zero (Palmer & Strobeck, 2003). In a study on male facial attractiveness and facial FA, it was shown that horizontal facial FA (HFA, aggregate of the absolute horizontal left-right difference of six distances from a vertical midline based on all bilateral landmarks) and vertical facial FA (VFA, sum of all vertical distances between seven bilateral pairs of landmarks) were inversely related to ratings of attractiveness ($N = 40$ target participants, $N = 79$ raters, Scheib, Gangestad, & Thornhill, 1999; see also Grammar & Thornhill, 1994). Further studies found FA to be associated with attractiveness perceptions even in the absence of direct visual cues, for example for rated attractiveness of participants' body odor ($N = 77$ target participants, $N = 87$

99 raters, Gangestad & Thornhill, 1998). Furthermore, vocal qualities have been shown to
100 negatively correlate with different measures of FA (e.g. bodily FA, Abend, Pflüger,
101 Koppensteiner, Coquerelle, & Grammer, 2015, $N = 42$ target participants, $N = 103$ raters;
102 Hughes, Harrison, & Gallup Jr., 2002, $N = 106$ target participants, $N = 13-17$ raters; Hughes,
103 Pastizzo, & Gallup Jr., 2008, $N = 76$ target participants, $N = 101$ raters), suggesting that voices
104 may convey information about DI.

105   Vocal qualities have also been related to mating success. For both sexes, opposite-sex
106 ratings of vocal attractiveness were related to reported age of first sexual intercourse, number
107 of sexual partners, EPC partners and number of partners by whom they had been chosen as
108 an EPC partner ($N = 96$, Hughes, Dispenza, & Gallup Jr., 2004). Vocal characteristics may hence
109 reflect aspects of mate quality and signal information on heritable fitness benefits (Hill & Puts,
110 2016).

111   Recent studies provided evidence for associations of vocal attractiveness not only with
112 bodily FA, but also facial FA. In Abend and colleagues' study (2015), the voices of women with
113 both more symmetric bodies and faces were rated as more attractive by male judges ($N = 42$
114 target participants, $N = 103$ raters). Hill and colleagues (2017) showed comparable effects
115 across three studies for facial FA. In study 1, men and women's ($N = 325$) vocal attractiveness
116 was rated by unfamiliar participants ($N = 1,127$) of the opposite sex. Facial FA was computed
117 as the aggregate of HFA and VFA (based on 2D photographs). Results showed an inverse
118 relationship between facial FA and vocal attractiveness in both men and women. In study 2,
119 in a mixed-sex sample of Hadza hunter-gatherers ($N = 65$), who are thought to have a higher
120 exposure to environmental stressors compared to Western samples which may influence the
121 development of FA, effects were in the same direction as in study 1, albeit not significant. In
122 a third study, the stimulus set consisted of 2D facial photographs ($N = 79$ males) and of 3D

face scans for a subsample ($n = 52$). Again, correlations were non-significant but in the predicted direction for both 2D and 3D stimuli. An internal meta-analysis (including their 3 studies and previously published work from Abend et al., 2015 and Hughes et al., 2002, the latter on bodily FA only), showed a robust negative association between facial FA and vocal attractiveness. Collectively, this suggests that vocal attractiveness may be an indicator of low DI and convey information on heritable fitness benefits. However, non-significant findings (studies 2 and 3 in Hill et al., 2017) call for independent replication to further assess the magnitude and robustness of these associations.

The heterogeneity of results may partly be explained by extant studies differing considerably in methodological respects. Hill and colleagues (2017) assessed facial FA using measures from both 2D photographs and 3D face scans, whereas most earlier studies used 2D photographs only. Somewhat surprisingly, Hill and colleagues (2017) observed a null correlation between facial FA measured from 2D photographs and 3D scans, questioning the validity or reliability of either of these methods. Since faces are 3D structures, measuring facial FA from 2D photographs may miss potentially important information from the third dimension, and hence using 3D scans should be the preferred method providing more complete measures of facial FA (Abend et al., 2015; Berssenbrügge et al., 2014; Ekrami et al., 2018; Hill et al., 2017). Moreover, most earlier studies measured FA using simple manual landmarks (e.g. Scheib et al., 1999), for which a diverse array of variants exists (e.g. horizontal and vertical FA, Hill et al., 2017; Scheib et al., 1999; Simmons et al., 2004; comprehensive FA, Penke et al., 2009), and which may miss important information such as dominant features of a face due to the limited number of landmarks (Ekrami et al., 2018). Geometric morphometrics have been proposed as an improved method capturing greater shape information (e.g. Abend et al., 2015; Claes, Walters, Vandermeulen, & Clement, 2011; Hill et al., 2017; for a review see

Mitteroecker & Gunz, 2009). In our study, we combined both favourable approaches by using 3D stimuli and utilizing geometric morphometrics. We employed a 3D spatially dense approach for measuring asymmetry, by non-rigidly mapping a symmetrical mask onto the 3D face scans and comparing the faces with their mirrored versions (Claes et al., 2011; Ekrami et al., 2018).

The main goal of our study was to replicate and assess the robustness of the previously reported association between facial FA and vocal attractiveness (Abend et al., 2015; Hill et al., 2017) in a sample of Western men and women, using an improved methodology of automatically measuring facial FA from 3D scans. Based on previous results (Abend et al., 2015; Hill et al., 2017), we hypothesized lower facial FA for males and females with higher rated vocal attractiveness, and that this effect would hold when controlling for facial attractiveness (since facial symmetry may indirectly increase vocal attractiveness via facial attractiveness, for example when individuals with more symmetric and hence attractive faces speak more confidently and attractively, Hill et al., 2017; Van Dongen & Gangestad, 2011). We further test for the correlation between 2D and 3D facial FA to examine the convergence of results between these two methods of measuring facial FA.

Methods

Participants. One hundred sixty-five men (age: $M = 24.28$ years, $SD = 3.25$, range 18-34) were recruited as part of a larger study on personality and hormonal reactivity (Kordsmeyer & Penke, 2019) and 157 women (age: $M = 23.20$ years, $SD = 3.45$, range 18-34) participated in a larger study on ovulatory cycle effects on, amongst others, mate preferences (Jünger, Kordsmeyer, Gerlach, & Penke, 2018). Due to sexual dimorphism in faces and voices (e.g. Puts, Jones, & DeBruine, 2012), results were analysed separately for both sexes.

3D facial FA measurement. Participants' faces were 3D-scanned twice for men and overall twelve times for women (thrice for each of 2 sessions during the luteal phase and 2 sessions during the fertile phase of their ovulatory cycles, of which the scans from the first luteal sessions were used, see Jünger et al., 2018 and Stern et al., 2019 for details) using a 3dMD face scanner. For each participant one scan was chosen with the most neutral facial expression and standardized head position, while some participants (males: $n = 28$, females: $n = 4$) had to be excluded due to poor scan quality or interfering facial hair for the males. We used a 3D spatially dense approach to measure FA in the faces (Ekrami et al., 2018). A symmetrical template face comprised of 7160 densely located paired vertices was mapped onto each of the faces in the dataset, using a non-rigid Iterative Closest Points (ICP) algorithm. The reflection of the faces were obtained by reversing the sign of the X coordinates of the vertices (the x-axis passes through the middle of the face) and then relabelling the vertices with their paired counterparts in order to re-gain compatibility of the original face and its mirror (Klingenberg, Barluenga, & Meyer, 2002). The original faces and their reflections were then aligned using a weighted Procrustes algorithm and the total asymmetry for each face was simply calculated by subtracting the mirrored face from the original (see Figure 1 for heat maps of average facial asymmetries). Following the conventional approach (e.g. Palmer & Strobeck, 2003), DA was defined as the average asymmetry of the sample set and FA was obtained by correcting the calculated total asymmetries for DA. For a subset of the men's sample ($n = 45$), facial asymmetry was measured from a second facial scan as described above to examine retest reliability of these automatic measures. These two measures were highly correlated ($r = .92, p < .001$), underlining the reliability of these automatic facial FA measures.

Figure 1. Heat maps showing average facial asymmetries based on 3D face scans for men (left) and women (right).

Note: N = 137 men, N = 153 women; unit of the scale is millimetres.

Facial FA from manual landmarks. To be able to directly compare results from these two samples with previously published studies (e.g. Abend et al., 2015; Hill et al., 2017), correlations of various facial FA measures based on landmarks manually placed on 2D facial photographs (for women only) and on 3D face scans (for men and women) with vocal attractiveness are reported in the supplementary (Table S1, for information on methods see supplementary).

Voice recordings. Men's voice recordings were extracted from semi-standardized video recordings, which captured participants describing what is great about themselves within one minute based on eight life domains (e.g. "friends", "sports", "humour") from which they were asked to choose three (for details see Kordsmeyer & Penke, 2019). The recordings were cut to a length of 5 seconds, beginning 5 seconds after the men started to speak. Female participants were recorded reading aloud a standardized voice passage

("rainbow passage", Fairbanks, 1960). The final sentence was used for voice ratings (mean length of the voice stimuli = 7.36 secs, $SD = 0.91$ secs). Since women's voice were recorded four times (twice per fertility status, see Jünger et al., 2018 and Stern et al., 2019), the recordings concurrent with the face scans from the first infertile session were used. After excluding five recordings for men due to technical issues and participants not wanting their recordings to be used further, the final stimulus sets comprised 160 recordings for men and 157 for women.

Voice ratings. One hundred nineteen raters ($n = 59$ men, age: $M = 20.21$ years, $SD = 4.05$) from a US-American subsample of a larger study on voice perceptions rated men's voice recordings on short- and long-term attractiveness, amongst others (Schild, unpublished master thesis). Raters were equipped with Sennheiser HD 280 Professional headphones and seated in private workstations. Raters provided information on their age, gender, sexual orientation, relationship status as well as on their German language knowledge, which indicated that most raters had no comprehension of German language (95.8 % were below the mid-point on a 7-point scale), ensuring our voice ratings were unbiased by spoken content. The 160 voice recordings were each rated at least 15 times by each sex (only long-term attractiveness was rated by 14 males and 15 females due to drop out of one male rater) on 7-point Likert scales using the item "How attractive does the speaker sound for a short-term, uncommitted sexual relationship?" for short-term and "How attractive does the speaker sound for a long-term, committed romantic relationship?" for long-term attractiveness, with the endpoints -3 = "very unattractive" to 3 = "very attractive".

Women's voice recordings were judged for short- and long-term attractiveness by overall $N = 42$ German raters ($n = 21$ women, age: $M = 25.00$ years, $SD = 5.04$), equipped with headphones and seated in private workstations. Raters provided information on their

age, gender, sexual orientation, relationship status and whether they were enrolled as a student. The stimulus set ($N = 157$) was split in half to reduce strain on raters, and each set was rated by at least 10 males and females (set 1/2: $n = 80/77$ voice recordings). The items “How sexually attractive is this woman?” for short-term and “How attractive is this woman for a long-term romantic relationship?” for long-term attractiveness were rated on 11-point Likert scales, with the endpoints $-5 = \text{“extremely unattractive”}$ to $+5 = \text{“extremely attractive”}$. Men’s and women’s voice recordings were presented in randomized order.

Mean ratings (of male and female raters) were used for each item for target men and women (interrater reliabilities: $ICCs > .77$, all $p < .001$). Since ratings of long-term and short-term attractiveness correlated significantly for men ($r = .82$, $p < .001$) and women ($r = .84$, $p < .001$), the means of short-term and long-term ratings were used for further analyses. On average, women ($M = 0.08$, $SD = 0.93$) received higher ratings of vocal attractiveness than men ($M = -0.28$, $SD = 0.61$; independent-samples t -test: $t = 4.04$, $p < .001$, Cohen’s $d = 0.45$)¹.

Face ratings. Standardized facial photographs were taken, while participants stood in front of a white wall directly facing the camera (Canon EOS 350D) with a distance of 2 m and were asked to show a neutral facial expression (with glasses removed). Two photos were taken of each man and overall four of each woman (1 for each of the 4 sessions, see above) and the most suitable photo (regarding neutral expression and head angle) was chosen for the subsequent rating study. Facial photos of 164 men (1 photo was excluded due to issues with the photograph) were presented on computer screens in randomized order. Twelve women (age: $M = 25.2$ years, $SD = 7.1$) rated facial short-term attractiveness (item: “How sexually attractive is this man?”) and long-term attractiveness (“How attractive is this man

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¹ Only for this independent-samples t -test, women’s ratings were converted to a 7-point scale (with the endpoints -3 to $+3$) to ensure comparability with men’s ratings.

for a long-term relationship?”) on 11-point Likert scales with the endpoints -5 = “extremely unattractive” to +5 = “extremely attractive”. The raters first previewed the whole sample, with each photograph displayed for 0.5 s, to provide the raters with a first impression of the whole sample. Additionally, for each target man raters were asked to what degree they knew him on a 3-point scale (1 = “not at all”, 2 = “know him by sight”, 3 = “well”). Data points where a rater indicated to know a given target man well (= 3) were excluded from subsequent analyses. Interrater agreements were high (for short-/long-term attractiveness, $ICCs = .86/.87$). Since ratings of long-term and short-term attractiveness were highly correlated ($r = .96, p < .001$), they were aggregated to get a measure comparable to women’s global facial attractiveness (see below).

Facial photos of 155 women (2 photos were excluded because they did not want their photographs to be used further) were presented on computer screens in randomized order and judged by overall 41 raters (21 women, age: $M = 19.9$ years, $SD = 1.5$) at the University of California, Santa Barbara on global facial attractiveness (item: “How attractive is this woman’s face?”) on 11-point Likert scales with the endpoints -5 = “extremely unattractive” to +5 = “extremely attractive”. To reduce strain on the raters, a three-minute break was taken after rating half of the stimulus sample. Interrater agreements were very high (for both short- and long-term attractiveness and for male and female raters, $ICCs = .92$).

Statistical analyses. Bivariate Pearson correlations were calculated for associations between facial FA and vocal attractiveness, separately for men and women. For robustness checks, we ran additional linear regression models, with facial FA as the independent and vocal attractiveness as the dependent variable, controlling for facial attractiveness in one model (as in Hill et al., 2017) and age as well as BMI in another model (as both may be related

to or confound FA measures, Manning, 1995; Penke et al., 2009). To examine whether the effect sizes in our sample on associations between facial FA and vocal attractiveness were statistically different from previously reported mean effect sizes, we conducted equivalence tests using the R package *TOSTER* (Lakens, 2017; Lakens, Scheel, & Isager, 2018). As the smallest effect sizes of interest (equivalence bound) we used the meta-analytic mean effect sizes of $r = -.20$ for men and $r = -.26$ for women reported in Hill and colleagues' study (2017, only including studies on facial but not bodily FA; see Kordsmeyer & Penke, 2017 for a similar procedure). Additionally, for a more conservative approach we used the confidence intervals' upper limits of the reported mean effect sizes ($-.06$ for men and $-.09$ for women, Hill et al., 2017; cf. Lakens et al., 2018; Perugini, Gallucci, & Costantini, 2014). Hence, we used $-.20$ and $-.26$ as the regular and $-.06$ and $-.09$ as the conservative bounds for men and women, respectively, to examine if our study's effect sizes significantly differ from these previously reported results (Lakens et al., 2018).

Data availability. The data and analysis script associated with this research are available at [link will be added later].

Results

Descriptive statistics including all ratings of vocal attractiveness and facial FA measures are shown in Table 1, and bivariate correlations between all main variables in Table 2.

Table 1. *Descriptive statistics for all variables measured.*

Variable	Men			Women		
	<i>M</i>	<i>SD</i>	<i>ICC</i>	<i>M</i>	<i>SD</i>	<i>ICC</i>
Facial FA	0.98	0.25		0.96	0.31	
Vocal attractiveness	3.72	0.61	.77/.83	0.13	1.46	.83/.83
Age	24.3	3.2		23.2	3.4	
BMI	23.98	3.81		22.45	3.34	
Facial attractiveness	-1.35	1.43	.86/.87	-0.15	0.99	.92/.92

Note. *ICC* = intra-class correlation (interrater reliability), *M* = mean, *SD* = standard deviation; vocal attractiveness rating scales for men/women: 1 to 7/-5 to +5; facial attractiveness rating scales for men and women: -5 to +5; *ICCs* for vocal and facial short-/long-term attractiveness, *Ms* and *SDs* for aggregates of short- and long-term attractiveness. *N* = 134-165.

Main results. Facial FA and vocal attractiveness were not significantly correlated in men ($r = .13$, $p = .15$) or women ($r = .06$, $p = .48$, Table 2, Figure 2). Similarly, when analysing short- and long-term vocal attractiveness separately, associations were non-significant (short-/long-term attractiveness, men: $r = .16/.08$, $p = .07/.36$, women: $r = .07/.04$, $p = .41/.59$). Equivalence tests revealed that for men, the effect sizes' confidence interval did not include the negative bound of $r = -.20$ (based on the meta-analytic mean effect size for men reported in Hill et al., 2017), showing that our effect size was statistically different from the previously reported mean effect size ($p < .001$, Figure S1). Even when following the more conservative approach and using the upper limit of the effect's confidence interval ($-.06$ in Hill et al., 2017; cf. Lakens et al., 2018; Perugini et al., 2014), our study's effect size was statistically different ($p = .02$, Figure S2). For women, the effect sizes' confidence interval did not include the negative bound of $r = -.26$ (Hill et al., 2017), again showing that our effect size was statistically different ($p < .001$, Figure S3). Also following the more conservative approach and using the effect's confidence interval's upper limit ($-.09$ in Hill et al., 2017), our study's effect size was statistically different ($p = .03$, Figure S4). Thus, we provide evidence for a potential absence of an inverse association between facial FA and vocal attractiveness, contrary to previous studies (Abend et al., 2015; Hill et al., 2017).

Figure 2. Scatterplot for the associations between facial fluctuating asymmetry and vocal attractiveness, separately for men and women.

Note: $N = 130$ men, $N = 148$ women; facial fluctuating asymmetry based on automatic measures.

Table 2. Bivariate Pearson correlations between all measured variables.

Bivariate correlations	Facial FA	Vocal attractiveness	Age	BMI	Facial attractiveness
Facial FA	-	.06	.05	-.02	-.10
Vocal attractiveness	.13	-	-.12	-.08	.09
Age	.14	-.07	-	.13	-.19*
BMI	.05	-.08	.08	-	-.36***
Facial attractiveness	.06	.28***	-.24**	-.21**	-

Note. Men ($N = 134$ -165) below and women ($N = 151$ -157) above the diagonal; * $p < .05$, ** $p < .01$, *** $p < .001$.

Robustness analyses. Adding target men's and women's facial attractiveness in one model and age as well as BMI in another model as covariates to linear regression models predicting vocal attractiveness from facial FA (separate models for men and women) revealed

only a significant effect for facial attractiveness on vocal attractiveness for men ($\beta = .27, p < .01$; other effects, for men: unsigned β s $< .16, ps > .09$, for women: unsigned β s $< .13, ps > .11$, Table S4). Thus, associations between vocal attractiveness and facial FA were robustly non-significant, also when controlling for facial attractiveness or age and BMI.

Facial FA from manual landmarks. Employing facial FA measures based on landmarks (vertical, horizontal and comprehensive facial FA measures, see Table S5 for an overview of facial FA measures) manually placed on 2D photographs (for women only) and 3D scans (for men and women) revealed no significant associations with vocal attractiveness for men (unsigned $rs < .09, ps > .33$, Table S1) or women (unsigned $rs < .14, ps > .16$, Table S1). For women, manual facial FA measures based on 2D photographs and 3D scans were not significantly correlated (grouped into vertical, horizontal and comprehensive facial FA measures, $rs < .19, ps > .053$, Table S2). Some of these manual facial FA measures showed small to medium-sized positive associations with the automatic facial FA measures for women (overall range for 2D/3D: rs between $-.01/.19$ and $.21/.33, ps$ between $.02$ and $.91$ for 2D, $ps < .02$ for 3D, Table S3), but not men (3D: rs between $-.09$ and $.12, ps > .16$, Table S3).

Discussion

Employing accurate and automatic measures of facial FA based on 3D face scans, we found no significant associations with target men's or women's observer-judged vocal attractiveness. These null associations held when controlling for their facial attractiveness as well as age and BMI. Equivalence tests revealed that our study's effect sizes were significantly different from previously reported effects (Hill et al., 2017). Thus, we provide robust evidence against a meaningful inverse relationship of vocal attractiveness with facial

FA as a proxy measure of DI (contrary to Abend et al., 2015; Hill et al., 2017; see Kordsmeyer & Penke, 2017 for a similar null-finding on bodily FA and mating success).

These results are in stark contrast to earlier studies on facial FA and vocal attractiveness (Abend et al., 2015; Hill et al., 2017), which may partly be explained by differences in methodology. In Hill and colleagues' (2017) three studies, facial FA measures were based on relatively few manual landmarks mostly placed on 2D photographs (3D scans were used only for a subsample in study 3), so that their results appear as less reliable and potentially less valid (due to the few landmarks capturing less shape information compared to automatic measures based on geometric morphometrics, Ekrami et al., 2018). While Abend and colleagues (2015) employed a geometric morphometrics method for facial FA (which was still landmark-based, however), they only used 2D photographs, thus discarding one dimension of shape information. Our study's methodology of assessing facial FA is advanced, using automatic geometric morphometric measurements based on 3D face scans (for a validation study see Ekrami et al., 2018), which should deliver more accurate facial FA data, while avoiding human error in manual landmarking (Berssenbrügge et al., 2014; Claes et al., 2011; Ekrami et al., 2018). Moreover, the sample in Abend and colleagues (2015) was relatively small ($N = 42$ target participants), so that the significant effect could be a false positive due to the estimation not being very robust (Schönbrodt & Perugini, 2013 recommended sample sizes of at least 250 for stable estimates). Overall, our results are at least as robust and accurate as earlier findings, given our relatively large samples and advanced method of measuring facial FA. Equivalence tests showed that our results were significantly different from these meta-analytic effect sizes for both men and women (Hill et al., 2017), even when more conservatively comparing our effect with the meta-analytic

confidence intervals' upper bounds (Lakens et al., 2018). Thus, robust evidence against a meaningful association between facial FA and vocal attractiveness is provided.

Earlier studies suggested a potential confound of associations with facial FA by facial attractiveness. Facial FA may directly affect facial attractiveness, independent of or beyond effects of underlying DI (e.g. Van Dongen & Gangestad, 2011). In the case of vocal attractiveness this confound could only be indirect. For example, presuming an inverse association between facial FA and facial attractiveness (e.g. Grammar & Thornhill, 1994; Komori et al., 2009; Scheib et al., 1999; Simmons et al., 2004), more facially symmetric people might feel more confident and speak more attractively (Hill et al., 2017). Our study's non-significant relationships between facial FA and vocal attractiveness were robust to controlling for facial attractiveness. Moreover, contrary to earlier evidence (Grammar & Thornhill, 1994; Scheib et al., 1999), in our study the correlations between facial FA and facial attractiveness were non-significant and close to zero (in the expected negative direction for women, positive for men). Our results should be more robust than extant findings (Grammar & Thornhill, 1994; Komori et al., 2009; Scheib et al., 1999), due to a considerably larger sample size and likely more accurate assessment of facial FA (automatic 3D-based vs. manual 2D-based measurement). This underlines suggestions that such a link may not be as straightforward and linear as previously assumed and requires further investigation (cf. Jones & Jaeger, 2019; Holzleitner et al., *in press*; Perrett et al., 1999; Simmons et al., 2004).

Our results may speak against vocal attractiveness directly signalling genetic quality in men or women, at least via a link with facial FA. However, vocal characteristics may still convey information about DI and heritable fitness benefits (Hill & Puts, 2016) and play a role in sexual selection (Collins, 2000). First, vocal attractiveness may more strongly relate to

measures of bodily FA than facial FA (for an inverse relationship between bodily FA and vocal attractiveness see Hughes et al., 2002). Hence, it is recommended to attempt to replicate these findings to establish whether vocal attractiveness may convey information about DI via its link with bodily FA instead of facial FA. Secondly, vocal attractiveness may still indirectly signal genetic quality, considering it has been debated whether FA provides a direct and reliable measure of DI or not (e.g. Van Dongen & Gangestad, 2011; in Van Dongen, Cornille & Lens, 2009 a significant inverse correlation between bodily FA and mating success faded after partialling out DA, the authors concluded that DI does not underlie the effect of bodily FA). As a third alternative, vocal characteristics may play a more direct role in sexual selection, not mediated by attractiveness, by influencing individuals' mating and reproductive success. Previous studies have shown positive effects on reported age of first sexual intercourse, number of sexual partners, and extra-pair copulation partners, for example (Hughes et al., 2004; but see Hill et al., 2013 and Kordsmeyer, Hunt, Puts, Ostner, & Penke, 2018 for null associations of vocal attractiveness with mating success).

Our null findings are strengthened by the fact that they converged for facial FA measured using manual landmarks (based on both 2D photographs and 3D face scans) as well as the automatic and spatially dense approach for both men and women. These manual measurements of facial FA based on 2D facial photographs and 3D face scans were not significantly correlated (in women), however, replicating Hill and colleagues' (2017) null correlation. Moreover, correlations of automatic, spatially dense 3D facial FA measures with manual measures based on 3D scans were descriptively stronger compared to those based on 2D photographs. Given that facial FA measures from 3D scans are described as superior (e.g. Claes et al., 2011; Ekrami et al., 2018), this pattern of results further questions the reliability and validity of earlier findings based on 2D photographs only.

Our findings might be limited by the fact that we employed standardized voice recordings in women only (rainbow passage, Fairbanks, 1960). Men's voice recordings were partly standardized, in that a range of topics was provided to choose from (e.g. "friends", "sports", "family"), but the men were free to talk about what exactly they liked for up to one minute (see Kordsmeyer & Penke, 2019 for more details and a further discussion of these recordings). However, ratings of men's vocal attractiveness appeared to be both reliable (in terms of high interrater agreements, comparable to those for women) and valid (as evidenced by a significant medium-sized correlation with observer-rated facial attractiveness, which is in line with the one ornament hypothesis, whereas for women we found no such positive association contrary to earlier findings, Feinberg et al., 2005; for a review see Feinberg, 2008), so that this aspect should not have seriously affected a potential association with facial FA.

To conclude, contrary to earlier studies (Abend et al., 2015; Hill et al., 2017), we provide robust evidence against a meaningful association between men's and women's facial fluctuating asymmetry and vocal attractiveness, as underlined by equivalence tests. Facial fluctuating asymmetry was measured using an arguably superior, automatic spatially dense approach based on 3D face scans. Additionally, we did not detect significant correlations using a variety of more conservative measures (manual landmarks based on 2D photographs and 3D scans), or when controlling for facial attractiveness, age and BMI. Thus, it seems that individuals' vocal attractiveness does not convey information on their heritable fitness benefits, at least not as manifested by facial fluctuating asymmetry as a proxy measure of developmental instability.

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